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ANALYSIS AND DEVELOPMENT OF SUSTAINABLE ENERGY FOR THE TELECOM/ICT INDUSTRY IN GHANA

BY
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AALBORG UNIVERSITY
DENMARK

ANALYSIS AND DEVELOPMENT OF SUSTAINABLE ENERGY FOR THE TELECOM/ICT INDUSTRY IN GHANA

by

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DENMARK

A thesis submitted to the Faculty of Engineering, Science and Medicine at Aalborg University in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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Curriculum Vitae

Kenneth Tsivor received MSc. Degree in Energy Engineering from South Bank University in London in 2000. Kenneth is now a PhD student in Aalborg University in Denmark. He is also a visiting scholar in New Jersey Institute of Technology, United States of America. His research interests include renewable energy applications, ICT in development and energy security.

Summary

Reliable and sustainable energy supply plays a significant role in the application of Information Communication Technologies (ICTs) in the various service and manufacturing sectors which have revolutionized the world economy in the past few decades. The interdependence of reliable electric power and telecommunication infrastructures have been the pivot around which economic, social and environment dimensions of sustainable development revolves. Telecom and electric power infrastructure are essential for effective ICT development which has been the prime mover of the functioning of modern society and economies. Many studies have proven that ICT is an all-purpose technology that has significantly changed the process of economic activities in the world in the past few decades. This is evident in the recent past economic development of United States of America and many European countries. ICT is also propelling development of many other countries across the world.

The emergence of mobile telephony in Ghana and many other African countries have led to rapid and unprecedented growth in wireless subscribers which can be used as a spring board for ICT development. The demand for electricity that can be provided for this growing telecom and ICT networks and facilities in Ghana is expected to increase, as a result of increasing population, passion for modern ICT services and development in industrialization. Currently, the urban dwellers in Ghana mainly have access to ICT facilities because about fifty nine percent (59%) of the population resides in the rural areas where access to basic telecom infrastructure and reliable electricity remains a challenge. Both urban and rural areas have limited or no access to grid power and this could deny Ghanaians from reaping the benefits of information age.

To overcome these challenge of electricity supply, it is important that electric power generation from naturally replenishing sources such as solar PV and wind energy are given high priority. Solar PV should be given the necessary support by policy makers, telecom operators and all other stakeholders in Ghana and other African countries because, it has the potential of possibly generating cheap and reliable electricity from sunlight, a renewable source that is readily available in abundant across the country and the entire continent.

The long term goal of this research is to contribute to the promotion of sustainable and reliable energy generation for the telecommunication industry in Ghana, and also to provide a basis for further research on alternative sources of power supply to the

telecom facilities which can minimize/eliminate the existing frequent electric power outages.

Due to the interdisciplinary character of the issues relating to both renewable energy and Telecom/ICT, the author uses approaches from various fields (policy analysis, economics and environmental protection) in quantifying the interdependent of telecommunication and reliable electric power system through the possibility of introducing renewable energy (solar PV and wind energy) to Ghana Telecom industry in an attempt to boost electricity supply to the mobile telecom operators. The analysis is qualitative and inductive. The research was based on extensive literature review; interviews with a number of experts, Telecom operators and other stakeholders; questionnaire for residents in the three selected study sites in Ghana and software simulation at three study sites using the load requirement for determining the renewable energy capacity in the hybrid system that will provide sustainable power.

The research reveals that though Ghana as a country acknowledges the importance of providing favourable environment for investment in both Telecom/ICT and energy industries, there are a number of policy and regulatory barriers that still needs to be addressed. The study also show that, the use of renewable energy systems are much cheaper and more reliable for effective operation of the Base Transceiver Stations. The various system configurations such as solar PV size, wind turbine size and battery autonomy of the system have been taken into account. The minimum renewable energy sources to supply the Base Transceiver Station loads in the three study sites were simulated with Diesel Engine Generator to find the optimal supply mix for each station. The outcome has been summarized in the table below.

BTS sites	Kabakaba Hill	Ada-Foah (1st operator)	Ada-Foah (1st operator)	Ada-Foah (2nd operator)	Jema
System	PV/Wind /DEG	PV/Wind /DEG	PV/Wind	PV/Wind/ DEG	PV/Wind/ DEG
Cooling System	***A/C***	***A/C***	Free Air	***A/C***	***A/C***
Initial Cost ($)	76,450	76,450	45,453	76,450	76,450
Cost of Energy (COE, $)	0.566	0.37	0.319	0.398	0.58
Net Present Cost (NPC, $)	228,103	149,196	77,881	237,078	233,807
Operation Cost ($)	11,731	5,626	2,537	4,690	12,172
Fuel Con./yr. (Litres)	5,613	1,576	No fuel	1,009	5,776
CO_2 Emission (kg/yr)	15,239	4,170		4,170	15,209

The use of renewable energy could help speedy propagation of ICTs to the grassroots in all parts of the country. It could inspire strong collaboration amongst the stakeholders within the industry namely the telecom operators, government, NGOs, academia and community information centres in the rural and remote areas based on a business model that will affect the sustainability of ICTs in order to lessen the digital divide. The research was carried out between April 2010 and May 2013. The research contributes to better understanding of the problems related to wider renewable energy and Telecom/ICT penetration. It also proves that the decentralized approach of power supply is ideal to surmount the current challenges of conventional power generation and this system is equally competitive. It equally provides decision makers in Ghana guidance on the needs and alternatives if a higher share of renewable energy is to be sought for development.

Resumé

Pålidelig og bæredygtig energiforsyning spiller en væsentlig rolle i forbindelse med anvendelsen af IKT (Informations- og Kommunikationsteknologi) i forskellige service -og fremstillingssektorer, som har revolutioneret verdensøkonomien i de seneste par årtier.

Den indbyrdes afhængighed mellem pålidelig el-forsyning og telekommunikationsinfrastruktur har været et centralt omdrejningspunkt for udviklingen af de sammenhængende økonomiske, sociale og miljømæssige dimensioner af bæredygtig udvikling. Telecom og el-infrastrukturen er afgørende for en effektiv IKT-udvikling, der igen har været primus motor for et velfungerende moderne samfund og økonomien. Mange undersøgelser har vist, at IKT er en universel teknologi, der har væsentligt har ændret processerne i de økonomiske aktiviteter i verden i de seneste par årtier. Dette er generelt tydeligt i den seneste tids økonomiske udvikling i USA og de fleste andre lande over hele verden.

Mobiltelefoni i Ghana og mange andre afrikanske lande udviser hastig og hidtil uset vækst i antal abonnenter, og dette kan bruges som et springbræt for IKT-udvikling. Efterspørgslen efter elektricitet, til denne voksende tele- og IKT-aktivitet i Ghana, ventes at stige som følge af en stigende befolkning, interesse for moderne IKT-tjenester og industriel udvikling. Da hele samfundet bliver mere og mere afhængig af informationssystemer, er forståelsen af den indbyrdes afhængighed mellem de forskellige infrastrukturer afgorende for den sociale og økonomiske udvikling. Hovedsagelig byboere i Ghana har i øjeblikket adgang til IKT-faciliteter, fordi omkring 59 procent af befolkningen bor i landdistrikterne, hvor de ikke har adgang til grundlæggende teleinfrastruktur og pålidelig elektricitet til at opretholde IT-virksomhederog generel IKT-aktivitel. Både by-og landområder har begrænset eller ingen adgang til el-forsyning, og dette kan forhindre ghaneserne i at høste fordelene ved informationsalderen.

For at overvinde disse udfordringer inden for elforsyning, er det vigtigt, at naturlige energikilder såsom solcelleanlæg og vindenergi er prioriteret højt. Solcelleanlæg bør f.eks. gives den nødvendige støtte fra de politiske beslutningstagere, teleoperatører og alle andre interessenter i Ghana og andre afrikanske lande, fordi det har potentiale til at skabe billig og pålidelig elektricitet. Solen er, en vedvarende kilde, som er let tilgængelig i rigelige mængder over hele landet og kontinentet.

Denne afhandling fokuserer på udvikling af en ramme til kvantificering af den indbyrdes afhængighede mellem telekommunikation og et pålideligt elsystem, idet

muligheden for at indføre vedvarende energi (sol- og vindenergi) i den ghanesiske teleindustri undersøges som en mulighed for at øge og stabilisere energiforsyningen til mobil teleoperatørerne. Undersøgelsen

bidrager med en analyse af de bidrag, som solcelleanlæg kan yder i økonomiske, sociale og miljømæssige udviklingssammenhænge. Strategien for undersøgelsen omfatter identifikation af udfordringer gennem rundspørge og interviews kombineret med gennemprøvede teknikker for energisystemsimuleringer med grundlæggende omkostningsanalyse.

Betydningen af denne forskningsundersøgelse er især belysning af de mulige bidrag fra sol- og vindenergi gennerm simulering af energiforbruget i de mobile transceiverstationer og dermed udvikling af bæredygtig energianvendelse inden for Telecom (SEAT modellen). De resulterende profilerne er beregnet til at blive anvendt til at vise pålideligheden af vedvarende energi telekommunikationsnet.

Vi har præciseret de vigtige spørgsmål, der skal behandles for at opnå en vellykket indførelse af solcelleanlæg til en bæredygtig udvikling af IKT i Ghana. Dette er foranlediget af erfaringerne med tilbagevendende strømafbrydelser og udsving, knaphed på dieselolie og tyveri på basestationer.

Afhandlingen beskriver proceduren for følsomhedsanalyse af indbyrdes afhængige systemer og præsenterer en praktisk anvendelse gennem simulering på basestationer forskellige steder i Ghana. Ifølge undersøgelsen er anvendelsen af vedvarende energi på telecom-basestationer pålidelig og økonomisk.

Der er anvendt både kvalitative og kvantitative forskningsmetoder med casestudier på tre lokationer, hvor forsyningsbehovet bruges til bestemmelse af kapaciteten af vedvarende energi i hybridsystemet, der kan producere tilstrækkelig energi. Dent tilstrækkelige energi matcher base stationens drifts belastninger og kan levere strøm uafbrudt uden megen forstyrrelse på telenettet. Dette system er designet med henblik på, at vedvarende energikilder alene kan tage sig af efterspørgslen fra BTS (base transceiver station) med et anlæg, der er teknisk og økonomisk muligt. Dieselgeneratorer blev brugt til at supplere op ved eventuelle kortsigtede udfald for at imødekomme efterspørgslen under dårlige vejrforhold og om natten ved systemsvigt. Den decentrale strømforsyning er ideel til at overvinde de aktuelle udfordringer inden for konventionel elproduktion, og dette system er lige så konkurrencedygtigt. Det endelige hybridsystem, der efter simuleringer blev valgt til hver af undersøgelsens lokationer, har de mindst mulige vedvarende energikilder, som er nødvendige for at matche belastningen, men bruger dieselgenerator som supplement. De forskellige systemkonfigurationer såsom solcelleanlæggets størrelse, vindmøllestørrelse og systemets batterikapacitet er taget i betragtning. Minimumsstorrelsen for vedvarende energikilder til at forsyne transceiverstationen de tre steder, hvor undersøgelsen blev gennemført, blev simuleret med dieselgenerator for at finde det optimale forsyningsmix til hver station. Resultatet er sammenfattet i nedenstående tabel.

BTS sites	Kabakaba Hill	Ada-Foah (1st operator)	Ada-Foah (1st operator)	Ada-Foah (2nd operator)	Jema
System	PV/Wind /DEG	PV/Wind /DEG	PV/Wind	PV/Wind/ DEG	PV/Wind/ DEG
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Fuel Con./yr. (Litres)	5,613	1,576	No fuel	1,009	5,776
CO_2 Emission (kg/yr)	15,239	4,170		4,170	15,209

De udvalgte systemer er langt billigere og mere pålidelige til effektiv drift af transceiverstationerne.

Brugen af vedvarende energi kan hjælpe med hurtig udbredelse af IKT til græsrødderne i alle dele af landet. Det kunne inspirere til stærkt samarbejde mellem de berørte parter inden for branchen nemlig teleoperatører, regeringen, NGO'er, akademiske kredse og bysamfundenes informationscentre i landdistrikter og fjerntliggende områder baseret på en forretningsmodel, der vil påvirke bæredygtigheden af IKT med henblik på at mindske den digitale kløft.

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“SEDEK’’ FOR EVER

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BTS	Base Transceiver Stations
BOT	Build Operate Transfer
CAPEX	Capital Expenditure
DCE	District Chief Executive
DCOP	District Commander of Police
ECG	Electricity Company of Ghana
EPA	Environmental Protection Agencies
GHG	Green House Gas
HOMER	Hybrid Optimization Model for Electric Renewables
IT	Information Technology
ICT	Information, Communication Technologies
IPCC	Intergovernmental panel on climate change
IEA	International Energy Agency
ITU	International Telecommunication Union
IUCN	International Union for the Conservation of Nature
NCA	National Communication Authority
NEB	National Energy Board
NREL	National Renewable Energy Laboratory
NPC	Net Present Cost

NEPAD	New Partnership for Development
NGO	Nongovernmental Organizations
OPEX	Operational Expenditure
OECD	Organization for Economic Cooperation and Development
PV	Photovoltaic
SEAT	Sustainable Energy Application in Telecom
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organizations
UNEP	United Nations Environmental Programme
UNFCC	United Nations Framework Convention on Climate Change
UMTS	Universal mobile telecom system
VRA	Volta River Authority
WCED	World commission on Environment and Development

Chapter 1: Introduction

1.1 Background

Social and economic development in today's world greatly depends on the functionality of critical infrastructures such as electric power grids, telecommunication systems, water networks and transportation infrastructures (Ouyang, 2014). Recently, there have been significant improvements in the efficiency of these infrastructure systems in meeting changes and growing demand (Ouyang & Duenas-Osorio, 2011). Where some technologies are interdependent, the efficiency of these infrastructures has improved their operations. Some good examples are in the vehicular traffic control systems and electric power supply. The efficiency of infrastructure has also enhanced business and financial transactions.

In the twenty-first century, telecommunication systems represent one of the fastest growing infrastructure sectors (Sahoo, Dash, & Nataraj, 2010) (Clemente, 2013). This growth has enabled the development of other essential infrastructures to use the Telecom/ICT technology and facilities to provide improved services (Sahoo, Dash, & Nataraj, 2010). For the purpose of our study, Information Communication Technologies (ICT) is described as the composition of a number of computer-based technologies, such as voice and data telephony, wireless local loop, cellular telephones and electronic media outlets (e.g. television and radio channels).

For example, in the transportation sector, information is collected from locations where automated sensors are installed, (at the traffic lights, strategic positions along the streets and on the highways) and transmitted to traffic control centers. Traffic signals are then remotely managed by control centers through Telecom/ICT technology in attending to any traffic abnormalities in general. Also within the electric power generation sector, information are sent via Telecom/ICT facilities in maintaining stability by using real-time information to calculate electric power demand and the total condition of the power transmission and distribution. A typical example of interdependence of infrastructure is the Supervisory Control and Data Acquisition (SCADA) Systems use for power transmission in many developed countries. This system depends on Telecom/ICT networks for continuous delivery of information about the transmission of electric power supply system (Wang, 2011). The electric power control center uses this information to issue appropriate instructions to match the demand of power from consumers to power generation.

Equally, the banking and financial systems have depended on Telecom/ICT for advancement in their operations. Telecom/ICT networks and facilities are used for the timely authorization of credit cards, instant trading in the stock market and the use of automatic teller machines (ATM). ICT have been embraced by a lot of people who believe that these innovations can play a significant role in shaping economic growth and improving gross domestic product (Sahoo, Dash, & Nataraj, 2010). ICTs have demonstrated the ability to enhance economic activities through improved manufacturing and employment capacity. The use of ICT also contributes to raise the general social level of citizenry through service delivery as well as help democratic participation of the citizenry and dissemination of government information (Ouyang & Duenas-Osorio, 2011) (Gruber & Koutroumpis, 2010).

ICT have help accelerate economic growth by increasing job opportunities, improved productivity as many organizations depend on it for their operational activities. Individually, ICT has made it possible for people to undertake economic activities such as bank transactions, transferring money to relatives, or booking tickets for public transportation. ICT has brought the world closer together and contributed to improved quality of social life.

The application of ICT innovations by many countries, has contributed to an increase in gross domestic product (GDP) as shown by the Organization for Economic Co-Operative Development (OECD) countries (Gruber & Koutroumpis, 2010). For example, within the European Union and OECD countries, ICT has been widely recognized to be an engine of growth. ICT has contributed to 5.6% of gross domestic product (The World Bank, 2009).

The economic effects of ICT on Ghana have not been quantified, but the telephone penetration density-mainly mobile- increased from 3.4% in 2002 to 52.4% in 2008 (Ghana Statistical Service, 2009). The rapid growth in Telecom/ICT enabled faster means of communication and reduced travelling to deliver simple messages. ICT application is therefore expected to have influence on government agencies in promoting social and economic development of Ghana (Gruber & Koutroumpis, 2010) (Baqir, 2009).

According to many comprehensive ICT research studies, telephones have been a major contributor to improved information flow (Thompson Jr & Garbaz, 2007). In the past, researchers have noted how landline telephones positively improved the economic development of organizations since the landlines increased the interaction of managers and their workers. Some researchers argue that the telephone has been pivotal in fostering socio-economic benefits of ICT (ITU, 2006), (Thompson Jr & Garbaz, 2007). Other researchers have described ICT as an innovation that improves the quality of life of the people who have access to the innovation by creating employment opportunities and help in democratic empowerment to all class of people through dissemination of government policies. ICT can improve health care delivery and poverty alleviation of citizenry of any country (Ibraghimova, 2014). Presently, most economic activities of every country depends largely on ICT. However, developing countries such as Ghana have to overcome the challenges of access to the technologies, the quality of services provided and most importantly, the cost element of provision and use of the technologies (Baqir, 2009).

Due to factors such as poor basic telecommunication infrastructure, poor management style of leaders, a lack of access to reliable electricity supply for telecom facilities, the high cost of service in the delivery of these technologies (e.g. high costs of bandwidth and ICT devices), and the lack of human-resource capacity, only 52.4% of the Ghanaian population have access to telecommunication (i.e. landline and mobile) as of 2008. Each of these factors have now become a limitation to ICT implementation in Ghana. Another limiting factor for ICT development can be attributed to the Ghanaian towns and village settlements, especially in remote parts of country. It is currently estimated that approximately 59% of the Ghanaian population live in rural and remote areas (Ghana Statistical Service, 2009) where access to basic telecommunication and electricity infrastructures are lacking. Although records from the Ghana Grid Company indicate that approximately 72% of the country has access to the national grid electricity supply (Ghana Grid Company, 2010), the quality of that supply is very poor. This is because the power generated is insufficient and the national grid is neither stable nor reliable (Ghana Grid Company, 2010). In the urban areas, telecom and electricity infrastructures are equally limited and their absence is hampering effective ICT development in Ghana (Ghana Statistical Service, 2009) as it is also not reliable for ICT purposes because of intermittent blackouts and power fluctuations. These blackouts and fluctuations are usually due to the low generating capacity, distribution challenges and high demand from local and regional populations (Ghana Grid Company, 2010).

The electric power supply deficiency led to regular routine power interruptions and unplanned power outages to all customers including the mobile telecom operators in the country. On average, customers enjoy an uninterrupted power supply i.e. without fluctuation and outages for only four hours per day. These power supply interruptions damage telecom/ICT equipment and causes breakdowns in communication. The only available alternative is expensive, non-cost effective diesel engine generators deployed across telecom operators' entire networks. Furthermore, these electricity crises are likely to worsen in the future, as increases in fuel and electricity costs comes with elevated costs for electric power generation and operations for the telecom company. All of these will result in higher costs in using ICT.

Accordingly, the purported benefits associated with ICTs are not yet fully realized by the Ghanaians. In order for Ghanaians to reap the maximum benefits of ICT, it is necessary to overcome the aforementioned challenges, especially reliable electricity supply which is a prerequisite for proper functioning of all ICT equipment (Bekele, 2010).

With increasing competition in the mobile telecommunication sector of developed nations, operators are moving towards the developing economies for their growth (ITU, 2014). These developing economies are not immediately attractive to investors, a situation that demands an increase in the subscriber base and expansion of the network's reach for their investment to be profitable. Consequently, this requires an increase in the core communication network equipment, power and cooling systems. For a developing country like Ghana to embrace the ICT innovation fully, the country needs an alternative and decentralized form of power generation that could reduce the existing challenges and provide sufficient power for the Telecom/ICT industry since the national grid is unreliable.

In spite of the enhanced activities and advantages of ICT on development, the innovation also has some setbacks (Houghton, 2010). The world today is confronted with issues of climate change that are attributed to burning of fossil fuel for energy generation. As energy is generated from fossil fuel, by-products such as carbon dioxide have negative effect on the environment.

Though, the electricity consumption by Telecom/ICT industry (i.e.3%) is currently not as high as other industries, the possibility of the consumption rising is high because the ICT industry is expanding by the day. As the industry grows, the electricity consumption of ICT will increase and contribute to the negative effects on the environment (GSMA, 2012) (Byrne, Hughes, Rickerson, & Kurdgelashvilli, 2007).

1.2 Research Problem

The emergence of mobile telecommunication technology has elicited unprecedented growth of ICT applications in developing countries (ITU, 2010). However, cost effective and reliable supply of electricity to the Telecom base Transceiver stations to sustain the Telecom industry remains a big challenge to the development of the mobile phone network particularly in Ghana. The immediate challenges that needs to be addressed in order that Ghana can reap the full benefit of ICT are how the Telecom/ICT companies can reduce the capital and operational costs of their operations. The secondary concern for ICT industry in Ghana will be managing the environmental issues as the industry expands.

Given the challenges (e.g. unstable electricity supply) regarding the smooth implementation and development of telecom and ICT sector in Ghana and other developing countries, using solar photovoltaics (PV) and wind energy could be considered as an attractive and sustainable solution.. Fortunately, electricity generated from resources that can be replenished naturally, such as sunlight and wind, are capable of delivering a sustainable electricity supply and reducing the burden posed by fossil fuels on the environment, especially in the less-developed countries of the world. It is envisaged that investment in PV Technology and wind energy will promote a decentralized business of electricity generation as an immediate answer to electricity needs of rural and remote communities and areas that do not have access to the grid electricity supply. Furthermore, these alternative energy sources will enhance businesses in areas where the supply is not reliable. This form of energy generation is expected to play an important role in the future of electricity production for the telecom industry, bridging the digital divide and also minimizing the carbon footprint of telecom and ICT development.

Ghana's peculiar problem are the necessary infrastructure such as electricity generation and access to modern Telecom facilities. Also the lack of appropriate local environmental conditions, the over dependence on external/international aid organizations, too much emphasis on established technology and global climate change are some other challenges (United Nations Environment Programme, 2014). Electricity supply is not readily available across the country and Telecom infrastructure is only accessible in the major cities and towns. Due to several reasons, Ghana is not having definite standard for investment in the Telecom industry and therefore turn to depend very much on external/international organizations for assistance. The country leaders are also very selective about the technology which sometimes turn out to be outdated and outmoded. Electricity supply from reliable and sustainable sources are part of the local conditions that are very important in the implementation of sustainable ICT industry since the base transceiver stations are the centers where messages and data to and from customers are processed and should always be in operation. The lack of reliable electricity increases the operational expenditure of the Telecom companies and also contribute to high emission of carbon dioxide (CO_2) since the Telecom companies ought to depend on diesel fuel generators (GSMA, 2012).

As the industry expands, there is an increase in the number of base transceiver stations, base station controllers and mobile switching centers and these leads to an increase in energy consumption in the mobile telecom industry (Fong, 2009). Again, the Telecom exchange equipment, including cooling systems, uses constant power irrespective of the load and time (Houghton, 2010). Currently, the technologies used by the telecom operators in Ghana at the base transceiver stations, base station controllers, and mobile switching centers are generally the Global System for Mobile communication and Terrestrial Microwave Equipment (i.e. Code Division Multiple Access) for their operations. These type of equipment consumes substantial amount of electric energy and they produces much heat as they operates. For effective operations of the equipment, air conditioning units are provided and the air conditioning units also add up to increase the electricity consumption.

(Keniston, 2003) also pointed out a unique cause of ICT failure in developing countries, thus the ICT developers are not familiar with the local challenges and therefore are found wanting during the implementation of the ICT activities.

While some of the local challenges can be addressed successfully by technological innovations, others require rethinking the fundamental tenets of our energy generation industry. Renewable energy generation and/or the production of electricity close to the Telecom facilities offers one viable solution to these local challenges. Generating electric power on the local scale or close to the Telecom facilities can increase security of supply in terms of reliability, stability and constant supply. These local measures/solutions can result in a significant reduction of transmission and distribution losses since no distant high tension poles, conductors and other accessories will be used. By utilizing local renewable energy sources, there will be no clearing of vegetation to make way for transmission lines, there will be less deforestation and pollution of the environment as the renewable energy produces negligible pollutants and also the electricity bills will be less. Furthermore, generating electricity locally will create new employment opportunities (OECD/IEA, 2015).

Due to policy, legal, administrative challenges, technical constraints and limitation perception of Ghanaians, there has not been significant application of renewable energy especially within the Telecom/ICT industry. But the encouragement I gather from this study portraits positive realization of great potential for electricity generation from solar and wind resources across the country and the great priority the government of Ghana attaches to electricity generation from renewable sources.

This research reveals the limitation of renewable energy application in Ghana and also proposes recommendations for overcoming the challenges. The study assess how the existing policy framework of Telecom and electricity generation have been structured and how the stakeholders in the industry contribute to planning and implementation of policies. Some other constraints identified were related to policy, regulation, administrative procedures and technical feasibility of renewable energy. Upon analysis and understanding the root causes of the constraints, the study suggests some recommendations that can improve the existing policy framework.

Since this research is the first of its kind in Ghana, it is necessary to introduce a pragmatic and sustainable strategy, which should be guided not only by short-term financial gains, but also the strategy should have long term repercussion on development of the citizen as well as address the challenges in which the technologies are embedded for good. Therefore, this study contributes to a better understanding of the problems related to renewable energy application in Ghana. It also provide guidance for decision-makers on the advantages of decentralized electricity generation. The study also contributes to knowledge by providing detail overview of potentials and technicalities involved in renewable energy application across the country. The study identifies and analyses renewable energy technical feasibility and economic viability in Ghana and could be used by investors as it provides detail account of the potential of solar and wind energy in the different parts of the country with focus on the case study of base station for mobile communication.

1.3. Benefits of Renewable Energy Application in Ghana.

Renewable Energy application shows great prominence in Ghana. Below are some benefits that can be derived from renewable energy application in Ghanaian telecommunication industry.

1.3.1 Security of Electric Power Supply in Ghana.

The well-known recognized contribution of renewable energy are (i) decrease in fuel imports dependence, (ii) reduction in dependency on the fluctuation in international oil price, (iii) diversification of fuel mix through the introduction of more energy sources (iv) reduction of vulnerability of diesel fuel theft, (v) reduction of blackout due to archaic equipment and distribution challenges, (vi) offer the option for Telecom operators having their own power to be used in case the national system fails. Ghana has depended upon oil imports for over thirty (30) years for electricity generation, and for several years, the price of oil has been increasing. Fortunately, renewable energy (solar and wind) are abundant in Ghana and capable of providing better quality and reliable electricity to Telecom facilities than what is being provided currently from the national grid.

1.3.2 Economic Benefits of Renewable Energy for Telecom in Ghana

The main economic benefit of renewable energy is the use of free fuels which is in abundance. Renewable energy can reduce the cost of electricity generation and bears less financial risks due to its size. Because renewable energy can be generated close to the Telecom facilities, several components can be avoided and that could reduce transmission and distribution losses and costs. The reduction in the transmission and distribution components becomes additional cost saving on rehabilitation and/or expansion of the transmission and distribution networks. Renewable energy can provide electricity in remote areas to serve the telecom facility. The units are flexible for easy installation and operation. Because of their relatively small size, they require lower investment cost than the conventional large scale power plants. Renewable energy can provide reliable electric power and reduce random and unpredicted power outage and power fluctuation which is the current practice from the national grid in Ghana.

1.3.3 Social Benefits of Renewable Energy in Telecommunications in Ghana.

Renewable Energy can increase comfort through the provision of improved power quality and reliability of supply that can eliminate blackouts. Renewable energy can provide electricity to remote areas where it is extremely expensive to connect/extend national grid. By installing Renewable energy close to Telecom facilities, Telecom operator(s) can reduce their electricity bills to a lower price.

1.3.4 Environmental protection benefits of Renewable Energy in Ghana

Little or no carbon dioxide is one of the significant benefits of RE technologies. RE (solar and wind) produces negligible amount of carbon dioxide emissions. There is less destruction of vegetation and no harm to wildlife because RE installations can be localized and there is no need for destroying vegetation for transmission lines. There is also completely no/less pollution from the solar and wind power systems.

1.4 Aim and Objectives

The long term goal of this research is to contribute to the promotion of sustainable and reliable energy generation for the telecommunication industry in Ghana, and also to provide a basis for further research on alternative sources of power supply to the telecom facilities which can minimize/eliminate the existing frequent electric power outages.

The immediate objective of this study is to investigate how the application of renewable energy enhance Telecom/ICT industry by describing the present state of power generation in Ghana, to access the potential of solar and wind resources and to identify existing policies for the promotion of Renewable Energy in Ghana telecom.

The research under the first objective is undertaken in order to reveal the factors that can contribute to the Renewable Energy application in telecom. At present, this is the first overview of its kind that combines information from many sources. The information gathered on both telecom policy issues and Renewable Energy applications is used as a basis for the analysis related to the other sections of the study. Also, the most statistical data in solar and wind energy resource as well as telecom penetration in Ghana have been gathered during the time of the study. Studies on the potentials of Renewable Energy in Ghana are reviewed in order to explore the opportunities of deploying the technology across the country and to evaluate other Renewable Energy potentials available apart from wind and solar.

To achieve the objective, the main actors and institutions (Telecom operators, Ministry of Communication, Ministry of Energy, Energy Commission, Volta River Authority, Electricity Company of Ghana, experts in energy and Telecom) are identical. Their capacity and co-operation were studied a little in order to provide a starting point for the research.

Another objective is to access the techno-economic viability of solar and wind in Ghana Telecom application.

Electric power generation and distribution have been planned in a centralized form by the state, therefore though Renewable Energy exhibit very reliable form of power generation, it is yet to be incorporated into the national energy mix of the country. The study touches on the forms of energy generation and their implications. Although information on the possible economic and technical limitations were gathered, other limitations such as policy regulating environmental and social issues are briefly toughed, mainly at the basis of expert information provided in interviews and personal communications.

The final objective for this study is to propose an alternative source of power to the unreliable grid supply at the base stations.

Ghana has depended on Electricity generation from hydro and thermal and power sources for more than two decades. These sources of electric power generation have never met the power demands of the population because of population growth in the urban cities where national grid electricity is available. Many rural and remote communities never had access to grid electricity. This study seeks to propose Renewable Energy as an alternative source of electric power to the unreliable grid supply currently available particularly in the Telecom base stations, which are uniquely positioned to accelerate the development of Telecom/ICT industry in Ghana.

1.5 Research Questions

This study has one key research question, in addition to several subsidiary questions. The main research question is: **How can renewable energy application enhance Telecom/ICT operation in Ghana?**

The subsidiary research questions are:

1. What are the critical factors influencing sustainable development of telecommunication and ICT use in Ghana?
2. How does the unreliable supply of electricity affect the operations of the mobile telecom operators?
3. How can a relevant framework be modeled to incorporate the challenges hindering sustainable ICT application?
4. Can renewable energy provide reliable electricity for the base transceiver stations in Ghana?
5. What will be the financial benefit/cost of renewable energy to the Telecom operator?

1.6 Motivation for the Research

First, the Ghana Telecom industry has depended on unreliable grid electricity and diesel engine generators for the operation of telecommunication facilities, so creating a reliable energy source to serve the industry is very important**.**

Secondly, no professional research has been performed to evaluate the use of solar and wind energy in the base transceiver stations in Ghana.

1.7 Research Limitations

The greatest challenge encountered during this study is that renewable energy is not a widely used form of energy technology for Telecommunications, especially in Ghana and so there is a limited literature. From theoretical point of view, it has been very challenging to choose one framework that could explain the blend renewable energy innovation with telecommunication and also be able to explain the circumstances of development in Ghana. This is because Ghana is a small developing country and its power generation is centrally planned and owned by the state. This makes it difficult to apply a well-established theories to the study. In addition, renewable energy for Telecommunication is a new innovation and requires interdisciplinary approach that is the reason why the study adopted different approaches.

Due to limitation of resources and time, relevant aspects such as regulation (support, rules and legislation to promote renewable energy) were discussed. During the study it became obvious that Telecom operators have no clear cut policies on energy use and that the administrative procedure was a big challenge encountered. The author tried to review as many relevant authorization from different ministries as possible, but it is possible that there are omissions due to adamant nature and reluctance in releasing inform by individuals.

Although some issues could not be discussed in detail or were omitted, the author believes that the study draws a clear picture of the challenge of electricity to the Ghana telecom industry as well as the potential opportunities for renewable energy application in Ghana.

The study anticipated lack of cooperation and reluctance from stakeholders in granting interviews and providing us with the necessary information. It was therefore not surprising that some of them turn us out. However, on the whole interviews were granted and supports were provided from various experts and stakeholders who were approached, for which the author is most grateful.

1.8 Methodology

1.8.1 Stages of the study

The study was conducted in three stages. The initial stage of the study was descriptive, where documents were reviewed. The second stage was both a descriptive and an exploratory study. This involves a combination of document review and interviews. The third stage is the Hybrid Optimization Multiple Energy Resources (HOMER) software simulation. The study is mainly qualitative in nature, with some quantitative data gathered to support the arguments.

1.8.2 Research Techniques

The technique adopted for the study were different in various parts of the study. In the first phase, renewable energy and telecom related issues (policy) were studied through identification of actors (telecos, experts) and institutions that are responsible for Telecom/ICT and electricity issues. The study used opportunistic sampling techniques which Miles and Heberman (1994) described in the research snowball or chain. According to them, the snowball technique relies on experts or documents in the area can suggest further reference to other documents and persons. In opportunistic sampling, the researcher takes advantage of the opportunities that emerge unexpectedly or by following new leads.

1.8.3 Data Collection

Two techniques of data collection were used; document review and interviews. The study of documents was a central part of each phase of the research. In order to reveal and understand the problems in detail, interviews were used. Data collected was converted to electronic form together with carefully managed information collected from documents, interviews and field notes.

The study depended extensively on review of document (legislative act, studies, studies, reports, position papers, publications policy document) from the various renewable energy sources and also from Telecom/ ICT areas.

With regards to interviews, two strategies were applied; semi-structured interview and interview for which questionnaire was developed (Mintron 2003). The first type of interviews were conducted in a form of informed discussions with experts and stakeholders (telecos, ministries of energy, ministries of environment, Volta River Authority (electricity generating company), Electricity Company of Ghana (electricity distributing company). The author had the opportunity to participate in a number of conferences and to work with companies having renewable energy projects. One such company is Solar light company in Ghana.

The second type of interview was with some opinion leaders in the selected study areas. These people were requested to respond to the questionnaire (included in Appendix B-3). The aim was to gather comparable information on electricity generation challenges, and opportunities in investing in renewable energy. Most of the stakeholders were interviewed in person but some of the questionnaires were mailed after the prior communication with the respondents.

The first type of interviews started from the planning stage of the research; September 2010 and continued until the completion of the first draft (August 2015). Most part of the second type of interviews that required completion of the questionnaire were carried out between May 2011 and June 2012. There were digital recordings and hard paper respondents from individuals in the selected study sites.

For the purpose of confidentiality the identity of the stakeholders interviewed are not disclosed.

1.8.4 Data analysis

Data analysis started from the time the data was collected in order not to compile the various data that can overwhelm the author. Three stages of data analysis were used; organizing information, developing ideas and drawing conclusion. Because the study is interdisciplinary in nature, the data were first organized in a "meaningful analyzable manner" (Singleton and Straits 1999). The data were categorized to correspond to the objectives of the research. Writing short memos was used to capture various ideas during the analysis. Lofland and Lofland (1995) described memos as a "small piece of analysis , usually a paragraph or two, that capture the emergent idea that help make sense of the reality one is encountering". The study also used pictures/diagrams to represent the relationship between the concepts (Strauss and Corbin 1990). The study draw up conclusions using Lofland and Lofland (1995) suggestion on rephrasing the author’s writings in order to make the meaning of research better. To check the validity of the information gathered, we looked at the data from different perspective, thus different data sources such as public document, studies and interviews (i.e.; data triangulation). During the interview stages of the research, we contacted the stakeholders to confirm and cross check issues where written document did not exist (Marshall and Rossman 1989). When there appeared inconsistencies from different stakeholder, we quickly explored the reason for the inconsistencies.

1.9 Overview of Research

The research strategy that was implemented for the present study included many components to ensure the study was properly implemented and completed.

After this brief introduction of the background explaining what prompted the study, the background, aims and objectives and the scope of the study, the following chapter present details of the current state of renewable energy, the opportunities they offer and the challenges.

Below we describe each chapter, one by one. The description gives the structure of the thesis, and at the same time it gives reading guidelines.

Chapter 2 - Literature Review: This section contains a comprehensive review of relevant literature on the previous studies mainly on Telecom/ICT development and the trend of energy generation both internationally and within Ghana. This preview helps provided a comprehensive understanding of the significance of the challenges confronting the Telecom industry/ICT and their interrelations with the electricity supply, sustainable development, as well as the appropriate theory base relating to the research problem as stated in Chapter 1.

Chapter 3 - Examines Telecom/ICT development, Electricity generation and its impact on development in Ghana. It provides overview of basic facts on Ghana´s development of Telecom/ICT and the energy resources capacities for solar PV and wind energy.

Chapter 4 - Theoretical Foundation: This chapter focuses on Technology, Organization and Environment (TOE) framework by Tornatzky and Fleischer (1990). TOE was used as the core theoretical foundation of this chapter.

Chapter 5 - Research Design and Approach: This chapter outlines the research approach and methods used in the study leading to a description of the research design adopted to answer the research questions stated in Chapter 1. The methods addressing data collection and information processes from the Telecom operators and other stakeholders are highlighted. The remaining portion of the chapter describes data analysis and study constraints.

Chapter 6 - Electricity and Telecom/ICT challenges in Ghana: Discussion of the detailed findings of the study. It begins with the power situation in Ghana and then touches on the technical, political and institutional challenges related to both the electricity sector and the Telecom industry.

Chapter 7 - Hybrid Optimization Model for Electric Renewables (HOMER) Simulation and Results: Focus on HOMER simulations to confirm or otherwise test the viability and technical feasibility of applying renewable energy in the base transceiver station in Ghana. It also discusses the outcome in relation to financial, technical, social and ecological dimensions of sustainability of renewable energy.

Chapter 8 - Discussion of results of the interviews and field survey findings. The chapter also introduced a discussion of the development of Sustainable Energy Application in Telecom (SEAT) model for Telecom and ICT industry in Ghana and other developing countries.

Chapter 9 - Provides a recap of the research and the main findings and indicates how these findings relate to academia and their practical implications.

Chapter 10 - Conclusion: the concluding chapter of the research provides a recap of the background of these studies. The chapter also outline the benefits of renewable energy and recommendations for acceleration and development of the Ghana Telecom industry.

Chapter 2: Context on Existing Knowledge

2.1 Overview

The purpose of this chapter is to present background information on Telecom/ICT development and energy generation in order to provide a clear understanding for today's features of ICT and energy issues and their implication for development and environment. The development of many nations and societies over the decades can be attributed to innovation acceptance that was supported by reliable energy supply and delivery. This chapter also discusses the requirement and impact of ICT on the energy sector and to be able to support enhanced ICT innovations in developing countries.

The definition of ICT varies considerably as it emerged from the combination of information technology and communication technology. Thus, ICT refers to a range of technologies for capturing, storing, processing, analyzing, transmitting and retrieving information (Rouse, 2012). It covers Internet information technology equipment, telecommunications equipment and services, media and broadcasting, network-based information services and other related information and communication activities (Rouse, 2012). For the purpose of the present study, ICT is used to represent Information Technology (IT), Information System (IS) and Telecommunication to comprise of all communication devices or applications that encompasses Internet, cellular phones, computers, radio, televisions, hardware and software networks, and satellite systems.

2.2 Introduction

The present era could be considered the "information revolution" which is driven by Telecommunication/ICT that has evolved through technological innovations. ICT has enabled a developmental increase of various sectors of our economy and social activities (Leblois, 2011) (Raach & Hippel, 2013). This was because the introduction of ICT has reduced the production time, changed processes and enabled new services through the computerized systems (Raach & Hippel, 2013).

Therefore, ICT is viewed as a reliable means for changing and modernizing educational systems, improving the health care sector and being used as a tool for economic growth.

According to ITU statistics, the development in fixed telephone lines, mobile subscriber and internet users has been encouraging (International Telecommunication Union (ITU), 2013). In particular, the phenomenal growth rates in the mobile sector have been able to increase the telephone penetration index in both the developed and developing countries. Though the growth of fixed - telephone and broadband subscriptions has been negligible, the upsurge of mobile communication has brought innovations into the telecom industry in developing countries, including Ghana (ITU, 2014)

The mobile - cellular subscriptions was 7 billion in 2014, corresponding to 96% penetration. This increase in mobile - cellular subscription can be attributed to the continuous growth in demand in developing countries. The growth in mobile-cellular growth in developing countries is twice as much as in developed countries in 2014 (please see Figure 2.1). The fixed - broadband penetration also continues to grow, albeit slowly (at 4.4% globally in 2014) because there was slowdown in developing countries. The global fixed-broadband penetration growth rate are expected to decrease from 18% to 6% in 2014. In developing countries (please see figure 2.6), fixed - broadband penetration was expected to grow at 3.5% in 2014 compared with 4.8% in 2011 (ITU, 2014).

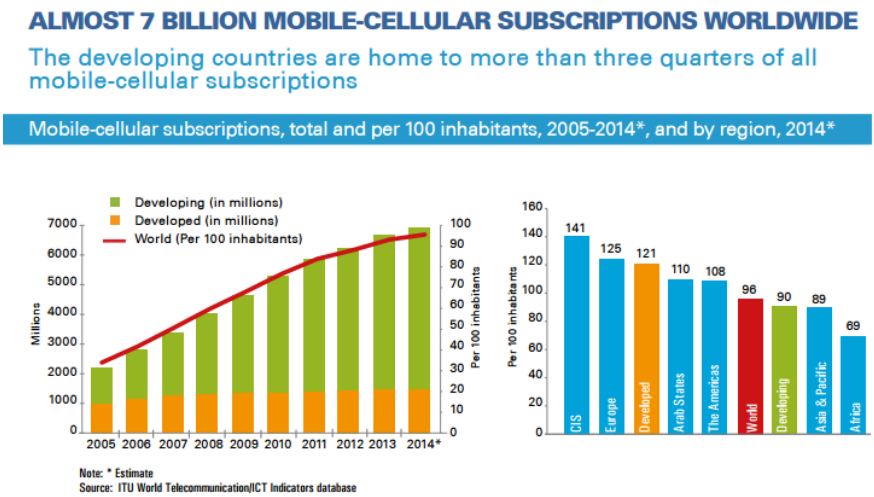


Figure 2. 1 Global Mobile – cellular Subscription

Source: ITU World Telecommunication/ICT Indicators Database.

With the introduction of enhanced mobile services, consumers could use short message services, multimedia messaging services and access the internet on their mobile phones (International Telecommunication Union (ITU), 2013). The advent of mobile telephony devices with increasingly powerful internet capabilities has changed the dynamics of global telecommunication (ITU, 2010). Mobile technologies have moved from ordinary voice transmitting and receiving devices to complete computing and communication that provide voice, text, pictures, video and other types of multimedia (ITU, 2014). Mobile technologies have changed the way we think, the way we interact and the way we do things. These technologies have made it more convenient to communicate using emails, short messaging services, multimedia messaging services, play interactive games online, downloads music, find friends, conduct business and banking transactions, purchase tickets, video conferences, implement educational training programs, among many others (Beardsley, Enriquez, Bonin, Sandoval, & Brun, 2010). There have also been continuous improvements in the bandwidth capabilities and reliability of mobile technologies, such as mobile networks, screen resolution and color displays. These improvements have made mobile phones a general-purpose tool.

Presently, many people see ICT as educative and entertainment platforms for promoting ideas and interests (Beardsley, Enriquez, Bonin, Sandoval, & Brun, 2010). Recently, the global proliferation of the mobile phone has actually boosted the prospects of ICT in socio-economic development (Welsum, 2008) and it is perceived that ICT can have a positive impact on state governance, improve education and healthcare delivery and promote intercultural relationships (Beardsley, Enriquez, Bonin, Sandoval, & Brun, 2010).

2.3 Telecom/ICT Market Structure and Development Trends

The two main factors that have contributed to the growth of Telecom/ICT over the years have been privatization and competition within the industry (Li & Xu, 2004). These factors have compelled an increase in market responsiveness to high demand for ICTs which have promoted innovative service development. ITU estimated that at the end of the 2014, there were about 7 billion mobile phone subscribers in comparison to 6.8 billion in 2013 and 5.4 billion in 2010 and 4.7 billion in 2009. It also estimated about 2.3 billion mobile broadband subscribers worldwide in 2014 (ITU, 2013) (ITU, 2014).

Between 2003 and 2013, the global Internet use increased indicating the level of acceptance of the innovation. The global Internet usage was approximately 3 Billion users as of the 31st December 2014 (Figure 2.2 and 2.3).

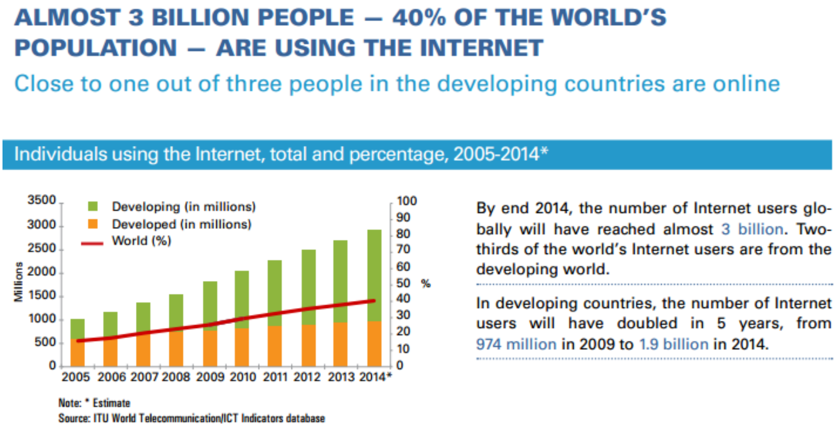


Figure 2. 2 Global Internet Users

Source: ITU World Telecommunication/ICT Indicators Database.

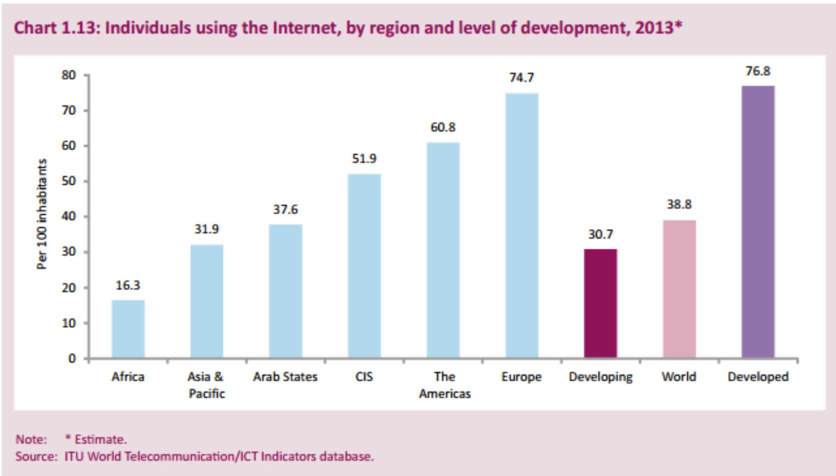


Figure 2. 3 Global Internet Penetrations

Source: ITU World Telecommunication/ICT Indicators Database.

Figure 2.2 and Figure 2.3 represent the statistics of people having access to modern information technologies such as the telephone and internet. Also figure 2.3 illustrates that at the end of the 31st December, 2013, about 60.8% of The Americas population and 74.7% of the European population had access to the internet, but in developing countries access to ICTs is different, especially in Africa which is lacking investment in infrastructure. Africa, which has a population of about three times that of America, had 1.4 fixed-telephone subscriptions per 100 inhabitants and 0.4 fixed broadband subscriptions per 100 inhabitants.

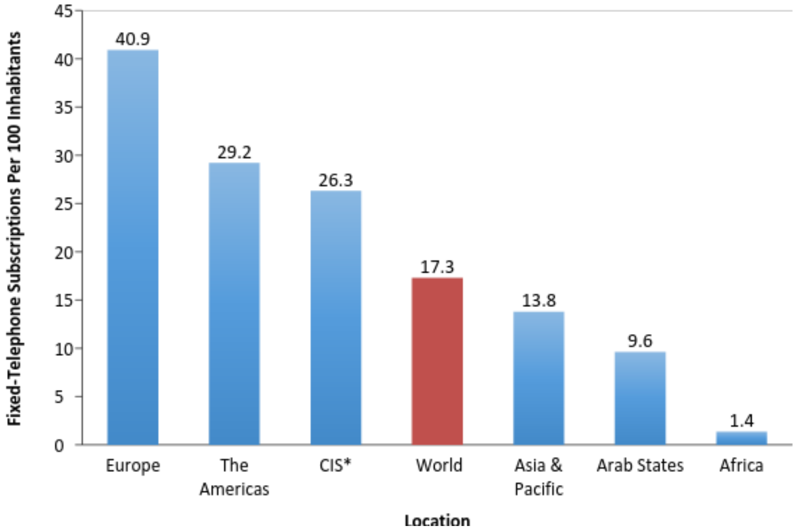


Figure 2. 4 Fixed- Telephone Subscribers in the world

Source: ITU World Telecommunication/ICT Indicators Database.

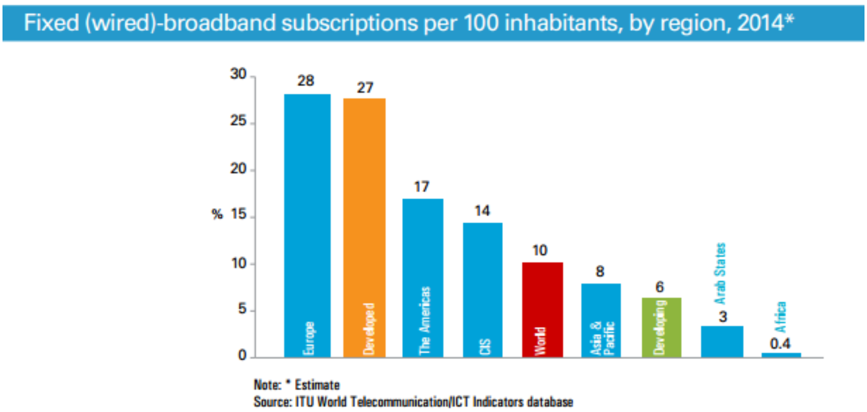


Figure 2. 5 Fixed (wired) – Broad Band

Source: ITU World Telecommunication/ICT Indicators Database.

World Region	Population 2011 Est.	Internet Users Dec31,2000	Internet Users Dec31,2011	Penetration % population	Growth 2000-2011	Users% of Table
Africa	1,037,524,068	4,514,400	139,875,242	13.5%	2,988.4%	6.2%
Asia	3,879,470,877	114,304,000	1,016,799,076	26.2%	789.6%	44.8%
Europe	816,426,346	105,096,093	500,723,686	61.3%	376.4%	22.1%
Middle East	216,258,843	3,284,800	77,020,995	35.6%	2,244.8%	3.4%
North America	347,394,870	108,096,800	273,067,546	78.6%	152.6%	12.0%
Latin America/ Caribbean	597,283,165	18,068,919	235,819,740	39.5%	1205.1%	10.4%
Oceania/ Australia	36,426,995	7,620,480	23,927,457	67.5%	214.0%	1.1%
World Total	6,930,055,154	360,985,492	2,267,233,742	32.7%	528.1%	100%

Table 2. 1 Internet Use in the World

(Source: ITU World Telecommunication/ICT Indicators Database).

Figures 2.4 and 2.5 and also the Table 2.1 illustrate that there is a need for improvement in infrastructural development in the whole of Africa. The poor and inadequate infrastructure is further coupled with limited computer literacy (International Telecommunication Union (ITU), 2013). The broadband subscription per 100 inhabitants in Africa was only 0.4, as compared with 8 for Asia, 17 for the Americas, 24.8 for Europe. The massive spread of broadband facilities in many countries enhanced their citizen's ability to subscribe to high speed internet access. The estimated number of Internet users in Africa in June 2012 was 167.3 million which was equivalent to about 7% of the worlds' 2.2 billion Internet user (Internet World Stats, 2012). Of these 167.3 million in Africa, Ghana comprised 2 million, or 1.19% whereas the Ghanaian population is 2.4% of Africa´s population.

Though the disparity in access to ICTs is most evident between countries, there is also inequalities within countries. Within countries, there is unequal distribution of resources and infrastructural development especially between urban, rural and remote areas. This issue leads to the challenge of being/not being able to access quality connections and being able to afford services so it brings about the digital divide (Dmitry.Epstein, Nisbet, & Gillespie, 2011). Countries with higher ICT penetration have attained high efficiency in business processes which has resulted in their products and service quality being very high (European Commission, 2008).

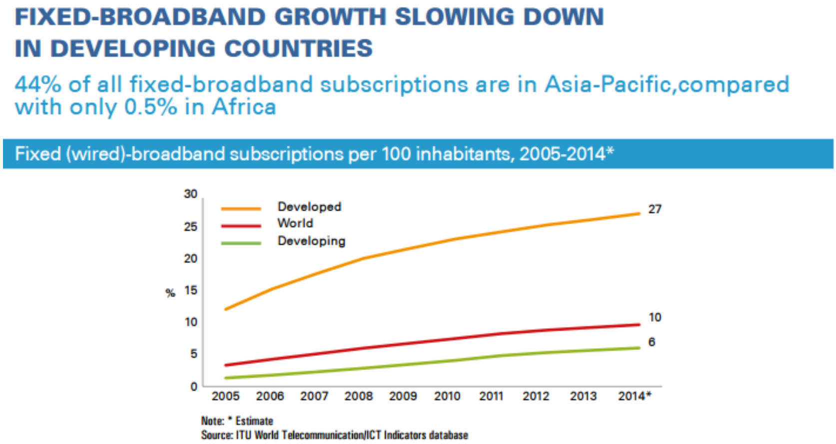


Figure 2. 6 Fixed- Broadband Growth

(Source: ITU World Telecommunication/ICT Indicators Database).

2.3.1 Telecom/ICT Development in Developing Countries

Telecom and ICT networks in developing countries have witnessed an unprecedented growth in the past decade. This has attracted considerable attention both locally and internationally due to the notion that ICT has the potential of impacting social and economic development in these countries (ITU, 2014). With the advent of mobile telephones, there is an increasing quantity of people in developing countries that are connecting to mobile networks (ITU, 2014) (International Telecommunication Union (ITU), 2013). Currently, Africa has now been identified as the region where mobile Telecom has improved communication (ITU, 2014). The proliferation of ICT in many developing countries has contributed to exponential growth of all sectors. It has also been accepted as being necessary for stimulating socio-economic development. There are some governmental plans and strategies for developing countries, but it is believed that more literature is required (Baqir, 2009). Out of the 6 billion estimated mobile phone users in 2011 as reported by ITU, developing countries account for about 4 billion. The Internet usage in Sub-Saharan African region increased from 4 million in 2000 to 139 million in 2011 (ITU, 2013).

2.4 The Impact of ICT on Development

The phenomenal growth in information and communication technologies (ICTs) has real implications for economic growth, in both developed and developing countries (Houghton, 2010). It has been argued that extensive applications of ICTs have improved the organization and performance of firms, which positively influences production sectors and consequently increases the total productivity factors (Gruber & Koutroumpis, 2010). The continuous growth of the industry has resulted in global inter-operator competition which has resulted in substantial contributions towards sustainable development through reducing environmental impacts. The OECD considers ICT as an innovation for improving capacities that provide access to services, create new opportunities for income generation, improve information and knowledge management within firms and organizations through reductions in transaction costs, and increase the speed and reliability of transactions among businesses. For example, the physical transportation of sending mail, banking services and buying goods has been reduced due to the use of email, electronic commerce and online banking (Gruber & Koutroumpis, 2010). ICT goods and services have contributed to the economic growth of countries like the United States, India, China, Finland and many others and can be assumed to be the gateway for successful economic and social transition (Gruber & Koutroumpis, 2010). According to Madon (2000), sustainable development embodies good health, education, poverty alleviation and are the foundation of socio–economic development. The concept of socio-economic development has been employed with varying perspectives to describe the quality of life enhancement from the individual to society and from organizational to international levels depending on many considerations (Baqir, 2009). The World Bank defines socio-economic development as the qualitative changes of citizens and restructuring in a country's economy in connection with technological and social progress (Gwatkin, et al., 2007). The World Bank used gross national product per capita (gross domestic product per capita) as its main indicator of economic development, which reflect an increase in the economic productivity and average material wellbeing of a country's population (World Bank, 2010).

From the many ICT research studies, the telephone has been a major contributor to information flow. The telephone has been a focal point around which economic benefits of ICT have been revolving (Thompson Jr & Garbaz, 2007). Campell (2008) indicated that the proliferation of ICT has dramatically changed the social aspects of citizen life. The telecommunication service sector, which includes services related to fixed telephony, mobile cellular networks and internet services are quickly increasing in all parts of the world. This increase has been driven both by the increasing popularity of mobile phones and Internet and the falling costs associated with technological innovations (International Telecommunication Union (ITU), 2013). The exceptional rate at which ICTs, particularly the mobile phone and the Internet, are flooding every country demonstrates that the world is advancing towards a global information society. Several studies over the past years have analyzed the relationship between the growth in telecommunication services and economic growth around the world (Baqir, 2009). These studies show that ICT has been recognized as a source of socio-economic development of many nations. ICT has been driving innovations, efficiency of organizations, introduced exciting competitions to improve productivity and has been fueling electronic businesses and creating jobs (Baqir, 2009)**.** Therefore, ICT has become a general purpose technology that has changed how economic activities are organized. The efficiency brought about by the use of ICT has also resulted in reduced manufacturing costs, which consequently lowers prices and causes increased demand (Berkhowt, Muskens, & Velthuijsen, 2000; Heiskenen & Jalas, 2003). Within the last 10 – 15 years research has demonstrated that the economic gains made through ICT application has contributed to the improved ways of doing things in the world (Qureshi, Keen, & Mehruz, Knowledge Networking for Development: Building Bridges across the Digital Divide, 2007). Literature has also illustrated that in order to bridge the digital divide gap, the ICT availability for lower-income persons should be developed (Qureshi, Keen, & Mehruz, 2007). Qureshi et al. (2007) made reference to a rural farmer in India who could use the Internet in transacting business and ordering seeds for his farm. On a related note, Avgerou (2003) suggests that using the theory of information and markets, greater access to ICT has paid off economically and has also provided improvement in the social lives of those who have access. This finding signifies that ICT can become a vehicle for socio-economic growth. Walsham and Sahay (2006) argued that future research on information systems in developing countries should endeavor to define "development'' to which ICT contribute. Therefore, as suggested by these researchers, it seems appropriate to review literature around the concept of "development''.

2.5 Impact of ICT on the Environment

Both the telecommunication sectors and the Information Technology (IT) industry also consumes a huge amount of energy. IT infrastructures create some environmental pollution both during its manufacture and disposal stages. Electricity generation from the conventional system produces harmful substances including carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxide (NOx) that are not eco-friendly and therefore pollute the environment. More specifically, the manufacturing of computers and its supporting materials, combined with the universal mobile technology emits high volumes of hazardous waste that is dangerous for the environment. For example, to transfer 1 gigabit of information from one mobile to another, about 25 kg of carbon dioxide (CO_2) is emitted (Emmenegger et al., 2004), (Hussain & Malik, 2012). (Deichmann, Meisner, Murray, Wheeler et. al., 2010) suggested that ICT was responsible for 2% of the global carbon emissions. It is also projected that the energy consumption in the telecommunication sector will be more than 200% of the current levels by 2017 (Yi Zhang, 2010). And ICT applications could reduce global CO_2 equivalent emissions by fifteen (15) percent in 2020 (Peter James and Lisa Hopkinson, 2009). Furthermore, ICT infrastructures along with computers consist of several toxic chemicals such as lead, chromium and mercury. The production and disposal of ICT equipment releases hazardous substances and also consumes large quantities of energy and water, thus producing many waste materials.

2.6 Impact of Energy Use in ICT

ICT itself consumes energy, therefore calls for corresponding higher energy consumption for both the processing power of central processing units and high capacity mass storage devices. The use of more powerful ICT systems to match the mass demand and the corresponding increase in power consumption, especially the mobile communications systems and the internet servers, have already seen increasing power consumption at a rate of 16 -20% per annum (Fettweis & Zimmermann, 2008; Jonathan, 2007; Vodafone, 2006).

Previous research demonstrates that the base stations and backhaul networks of the cellular communications network operators have a power consumption of 60 billion kWh per year, and this corresponds to about 0.33% of global electricity consumption (U.S Energy Information, 2007). Ericsson (2007) also released similar findings, which estimate that mobile network power consumption is responsible for 0.12% of primary energy use (Gandhi & Newbury, 2011; Yan, Zhang, Xu, & Li, 2011). The power consumed in the base stations themselves is about 80% of the total energy consumed in the entire operator’s mobile network (Vodafone, 2006).

The servers farms and the cellular network are estimated to consume energy that was close to 10% of the electricity produced from nuclear power stations across the world in 2005 (U.S Energy Information, 2007). This is equivalent to approximately 130 million tons of carbon dioxide emission (UN Statistics, 2009). According to Fettweis and Zimmermann (2008), the total power consumed by data centers is less than the total power consumed by the Internet (e.g. all routers and switches; see Figure 2.7). It is also estimated that the total energy consumed by the entire public switched telephone network (PSTN), the mobile cellular wireless network infrastructure and Internet is close to 3% of the total electrical power demand in the world (Arnold, Richter, Fettwei, & Blume, 2010).

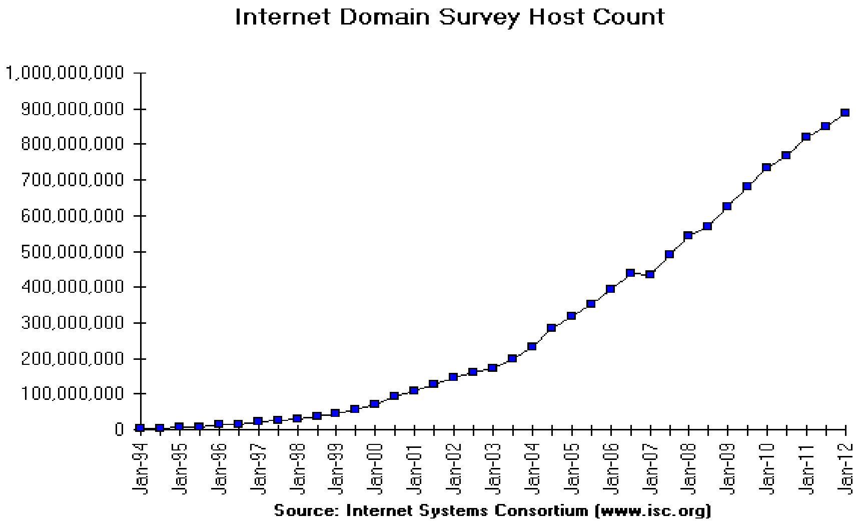


Figure 2. 7 Internet Power Consumptions

(Source: Internet Systems Consortium- www.isc.org).

2.7 Energy Consumption of ICT Use

The energy consumption within the ICT sector can be divided into six significant segments (Figure 2.8). These segments are: the fixed telephone network (15%), the mobile telephone sector (9%), data centers (23%), the local area network (7%), printers (6%) percent, and PCs and Monitors (40%).

When evaluating power consumption of Telecom and ICT devices, one needs to consider that the premises where the equipment are located needs to be cooled and avoid any power failure. This is express in as Power Usage Effectiveness (PUE) overhead which denote the factor by which the equipment is to be multiplied in order to know the total power consumption (i.e. equipment + overhead).

Fixed Line Access:

In fixed line access, the power per subscriber is stable because each subscriber has dedicated connection. Fixed line technologies such as digital subscriber lines (DSL) modem in the customer premises consumes 5 - 10 watt, while the gateways for optical networks also tend to have higher energy consumption than the DSL.

Asymmetric digital subscriber lines (ADSL) equipment consumes 1 - 2 watts per subscriber, Very- bit- high - rate digital subscriber lines (VDSL) equipment consumes 3 - 5 watts per subscriber. While optical network equipment consumes 10-20 watts per connection.

Wireless Access Network:

In wireless networks, base stations have highest power consumption. A Base station is defined as an equipment needed to communicate with the mobile station and the backhaul network. The power consumption in wireless network per subscriber depends on the subscriber density in the coverage area. High Speed Packet Access (HSPA) consumes about 68 watts per subscriber because of its low frequency. Mobile Worldwide Interoperability for microwave access (WiMAX) consumes approximately 2.9 kW per base station and a range of 340 metres. Long Term Evolution of 3G (LTE) consumes about 3.7 kW per base station, and a range of 470 metres. However, comparing power consumption per user for a subscriber density of 300 users per km^2, LTE performs best with a power consumption of 18 watts per subscriber followed by WiMAX with power consumption of 27 watts per subscriber (Vereecken, et al., 2011).

Core network:

The function of core networks is to transfer traffic streams between different sites by using high-end and low-end routers. Though the high-end routers are more efficient, they consume more power than the low-end routers. On average, present day core router consumes about 0.05W/Mbps. It is estimated that at ADSL access bit rates (8 Mbps), the core consumes about 0.24W/subs. As the access rate increases to 100Mbps, the power consumption will increase to approximately 3W/subs (Vereecken, et al., 2011). Currently, the power consumption in core networks is significantly lower than the access network, however, with increasing bit rates the power consumption of core networks will increase.

Devices in Customer Premise(s):

The power consumption of devices under fixed line technologies, such as DSL modem in customer premise consumes between 5 and 10 watt, which is higher than the power consumption in the access network. Home gateways for optical networks also tend to consume more energy than their DSL counterparts. In wireless networks the power consumption of the mobile stations are much lower since these are designed for mobile application(s), which require low power consumption for long autonomy times.

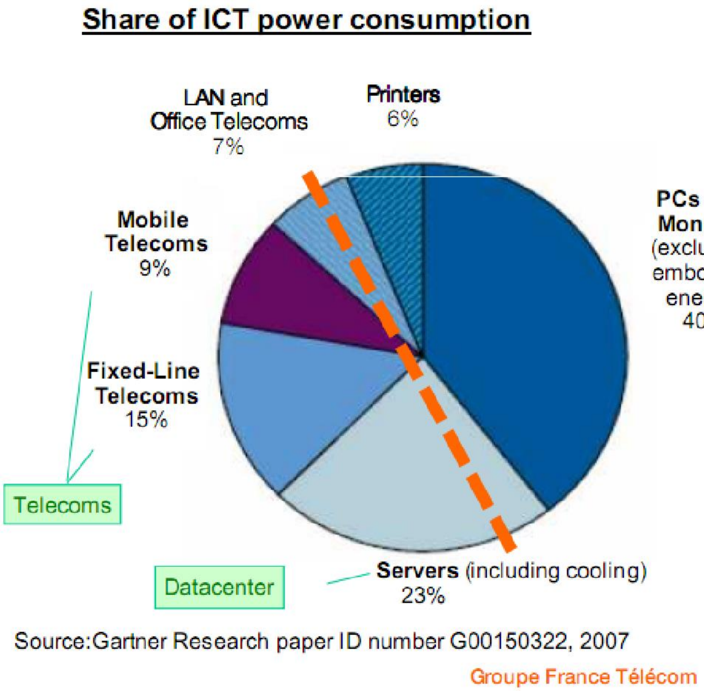


Figure 2. 8 Energy Consumptions in Different Sectors of ICT (Azeddine GATI.2007)

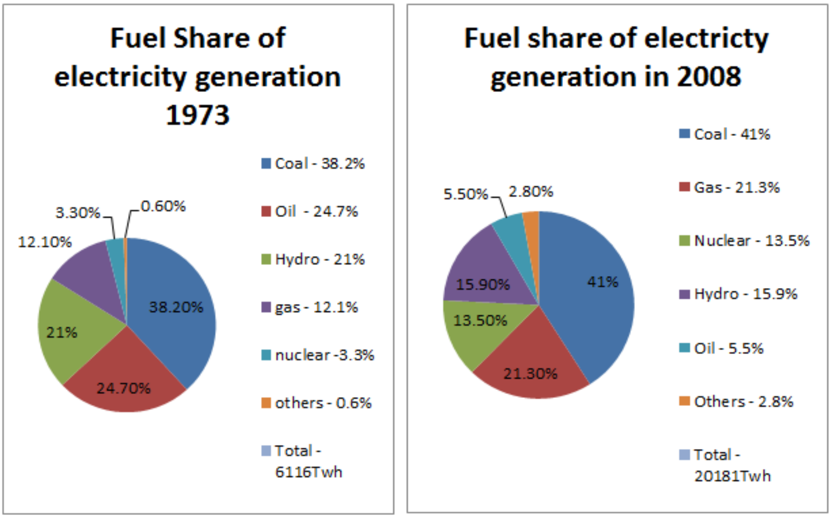
(Source – Gartner, 2007).

2.8 Electricity Generation Trend

Electricity generation and supply can be traced back for many centuries and different forms of energy generation from different resources have been with us from the early stages of human civilization (International Energy Agency, 2010). The known forms of energy production can be classified as renewable and non-renewable sources. The renewable sources are hydro-energy (e.g. tides, waves and rain), solar energy (e.g. photovoltaic, thermodynamic and concentrating), wind energy and geothermal energy. These renewable sources do not emit greenhouse gases. The non-renewable sources are oil, coal, gas and nuclear. Through technological advancement, resources such as coal, oil, nuclear, hydro and gas have been the preferred means of electricity generation and have propelled industrial development in many nations.

2.8.1 Electricity Generation

The demand for electricity greatly contributed to the evolution of modern civilization through the development of machines for transportation, communications and many others. According to the International Energy Agency (2010), in 1973, the electricity generation was 6116Twh. At that time, the fuel shares of electricity generation were 38.3% for coal, 24.7% for oil, 21% for hydro, 12.1% for gas, 3.3% for nuclear and other forms of generation were only 0.6% (International Energy Agency, 2010).



Fuel share of World Electricity Generation in 1973 and 2008

(Source: IEA, 2010)

Figure 2. 9 Fuel share of electricity generation in 1973 and 2008

(Source: IEA, 2010).

Though electricity generation increased to 20181Twh by 2008, there was a 5.5% drop in the use of oil. However, coal, gas and nuclear resources for energy generation increased to 41%, 21.3% and 13.5%, respectively. In addition, there was a 2.8% increase in renewable sources; however, there was a 15.9% decrease in hydropower (International Energy Agency, 2010).

2.8.2 Electricity Scenario in Developing Countries

Almost all developing countries have some kind of renewable energy resource that can be used for electricity generation. The region of Sub-Saharan Africa has an abundance of solar, wind, hydropower and geothermal resources (Organization for Economic Cooperation and Development/International Energy Agency – OECD/IEA, 2010). However the amount of electricity production does not correspond with the energy resources that are available. According to OECD/IEA (2010), about 1.4 billion people do not have grid electricity supply in developing countries, which indicates a serious energy deficit. The worse culprit is Sub-Saharan Africa, including Ghana which forms 38% of this figure.

A global projection for 2015 indicates that the total number of people without electricity will still be 1.4 billion (International Energy Agency, 2011). Though there will be an increase in access to electricity in developing countries from 75% to 81% by 2030, approximately 1.2 billion people will still be without electricity. In Sub-Saharan Africa, the projection shows an increase in access to electricity by 2030; however, the region will attain only 50% access to electricity as compared with 31% in 2009 (International Energy Agency, 2010).

	2009				2015		2030	
	Rural	Urban	Total	%	Total	%	Total	%
Africa	466	121	587	42	636	45	654	57
Sub-Saharan Africa	465	120	585	31	635	35	652	50
Developing Asia	716	82	799	78	725	81	545	88
China	8	0	8	99	5	100	0	100
India	380	23	404	66	389	70	293	80
Other Asia	328	59	387	65	331	72	252	82
Latin America	27	4	31	93	25	95	10	98
Total (Developing Countries)	1229	210	1438	73	1404	75	1213	81
Middle East & others	1232	210	1441		1406		1213	

Source OECD/IEA Energy Outlook 2010

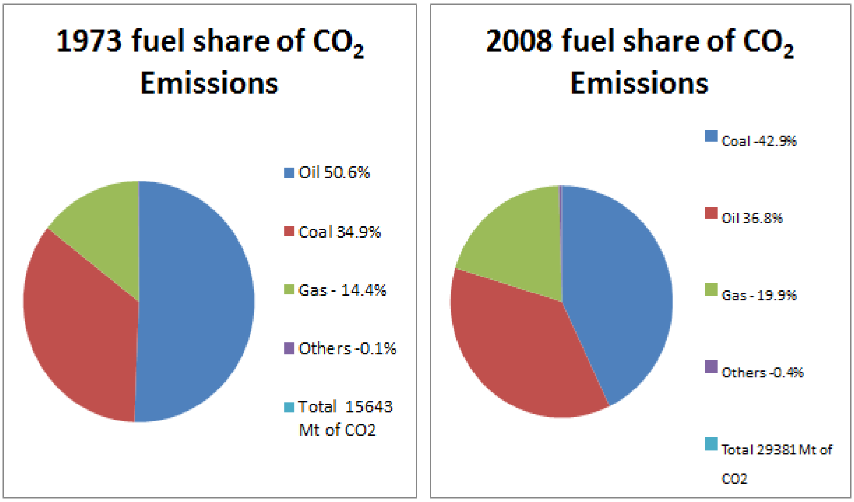
Table 2. 2 Electrification Rates of Developing Countries (million)

Source: OECD/IEA Energy Outlook, 2010)

2.9 Carbon Emissions

Though the percentage of oil used in power generation had decreased between 1973 and 2008, the total volume of dependence on fossil fuel resources had increased. According to IEA, carbon dioxide emissions have doubled between 1973 and 2008.

The total carbon dioxide emission in 1973 was 1564Mt with a breakdown as follows: oil (50.6%), coal (34.9%), gas (14.4%) and the remaining forms (e.g. renewable) comprised of the remaining 0.1%. In 2008, the total carbon dioxide emission was 29,381 and the percentage distribution changed slightly. More specifically, for 2008, the breakdown was as follows: coal (42.9%), oil (36.8%), gas (19.9%) and the remaining forms comprised of the remaining 0.4%. These values illustrates that atmospheric pollution was increasing (International Energy Agency, 2010; International Energy Outlook, Energy Information Administration Independent Statistics and Analysis, 2009).



Fuel share and Regional share of Carbon Dioxide Emissions in 1973 and 2008.

(Source: IEA, 2010)

Figure 2. 10 Fuel share and regional share of carbon dioxide emissions in 1973 and 2008

(Source: IEA, 2010).

With IEA's (2010) prediction that energy consumption will continue to rise at the rate of 1.6% per annum, it implies that by 2030, the world's energy consumption will increase by 50%. Though Birol (2006) also predicts that there will be sufficient energy resources to fulfill the global demand, what is certainly not clear is whether the Earth's ecosystem can sustain the negative effects associated with the trend of energy generation.

2.10 Environmental Concern

The concern about the environment has attracted widespread attention. The climate change issue has largely been attributed to the burning of fossil fuels for power generation (T.P.Hughes, et al., 2003). When fossil fuel is burnt, the by-products are greenhouse gases, such as methane and carbon dioxide, which contributes to climate change (Birol, 2006). Eighty percent of greenhouse emissions have been estimated to come from power generation (Birol, 2006). From the 1980’s, most national leaders from industrialized regions became concerned about the alarming manifestations of environmental degradation. The rise in the world’s average ambient temperature became a matter of international concern and a major challenge of humanity (T.P.Hughes, et al., 2003). “Global warming”, “climate change” and “greenhouse effect” are common expressions used in describing the threat to humans and natural ecosystems as a result of carbon dioxide (CO_2) and other gases that trap heat within the atmosphere. When sunlight reaches the Earth’s surface, some of the sun rays are absorbed to warm the Earth and the rest are radiated back into the atmosphere. Due to the substantial amount of greenhouse gas emission (e.g. CO_2, methane - CH_4, nitrous oxide - N_2O, hydro fluorocarbons - HFCs, Per fluorocarbon -PFCs, and sulfur hexafluoride - SF_6) coming from the burning of fossil fuel, these greenhouse gases prevent the heat energy (long wavelength) from escaping into the atmosphere. The re-radiation of this heat energy is called the greenhouse effect.

From 1990, climate change, global warming and predictions became a topical issue in international forums. The Earth summit held in Rio de Janeiro, Brazil became the focal point for decision making on climate change and led to the establishment of the Intergovernmental Panel on Climate Change. Even though, it is complex and difficult to accurately predict the full impact of climate change, the evidence from modeling studies as interpreted by the Intergovernmental Panel on Climate Change indicates that global mean temperature may increase by 1.4ºC to 5.8ºC and there will be a doubling in the concentration of carbon dioxide in comparison to 40 to 100 years ago (IEA, 2010, 2011). The consequences of climate change due to a variety of human-induced sources (Figure 2.11) could affect human and animal life, cause scarcity of water, decrease crop growth and output. It could also lead to vulnerability of human settlements and infrastructure as well as melting the polar ice caps and change the composition of the atmosphere (International Energy Agency, 2011).

In an attempt to address/manage and control the rate at which human activities cause climate change, an international intervention “Kyoto Protocol” was established in 1997 by the United Nations Framework Convention on Climate Change (UNFCC). This was a worldwide consensus to reduce emission of the six greenhouse gases over specified timelines (Byrne, Hughes, Rickerson, & Kurdgelashvilli, 2007) (Reddy, Hodge, & McKinion, 1997) (UNFCCC, 2008).

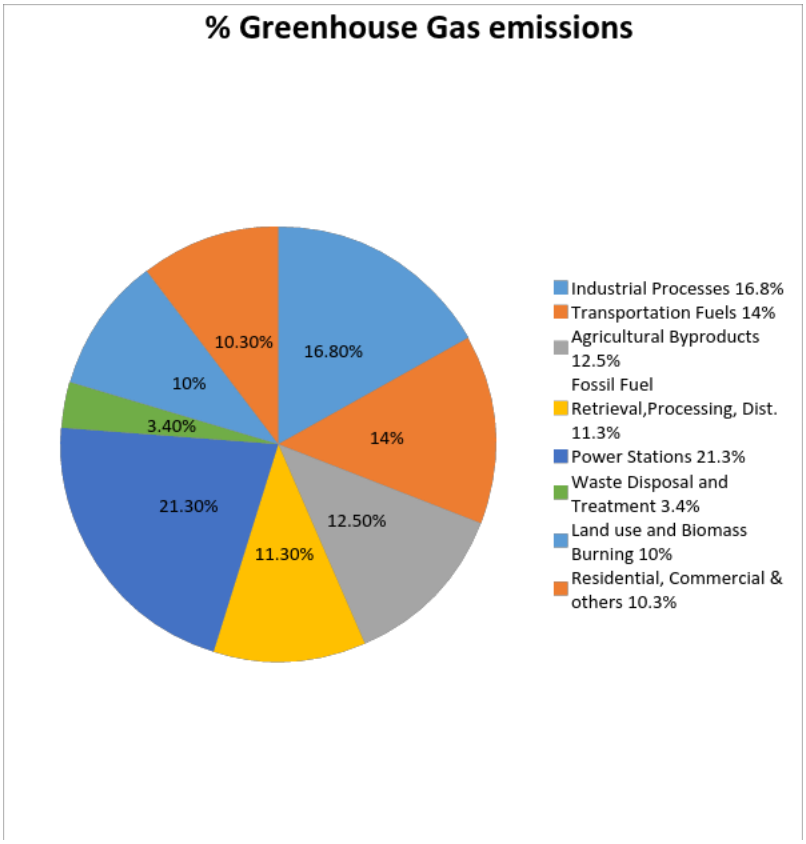


Figure 2. 11 The Percentage of Greenhouse Gas Emission from the Various Sectors.

Source: International Energy Agency, 2011)

As an extension to the Kyoto Protocol, another world conference on climate change, the Copenhagen Summit in 2009, was organized by United Nations Climate Change. This summit acknowledged the reality of climate change and agreed that some action should be taken to reduce ambient temperature increases to below 2°C. In order to achieve this target, a set of policy instruments were created to minimize emission at the lowest cost through innovative policy initiatives that promote activities related to greenhouse gas emission trading and use of renewable energy.

2.11 Initiatives to Combat Climate Change

Group of environmentalist, such as World Wildlife Fund (WWF), Greenpeace and other groups are promoting renewable energy in an effort to improve energy efficiency as a probable solution to climate change. For example, many countries of the European Union has a targeted 20% reduction in energy consumption, 20% reduction of greenhouse gas emission, and 20% increased consumption of energy from renewable sources by 2020 (LLOVET, 2010).

Telecom operators are also adopting renewable energy use as part of their corporate social responsibilities with the goal of reducing their networks' carbon footprint, while network vendors are striving to reduce the power requirements of their equipment (LLOVET, 2010). The United States, through Renewable Portfolio Standard (RPS), has mandated electricity providers to collectively generate 2,000 MW of additional renewable energy by 2009 and mandated companies to support renewable energy generation (International Energy Outlook, Energy Information Administration Independent Statistics and Analysis, 2009; State Energy Conservation Office, 1999). The United Nations Environment Program is also helping the governments of developing countries to reduce the developmental barriers of renewable energy technologies (OECD, 2009; UNEP RISOE CENTER, 2008). In Asia, 32 Telecom companies were signatories for incorporating renewable energy in their network as the way for the future (Normand, 2010). Africa and the European Union have agreed to undertake a joint effort to promote access to sustainable energy usage to at least 100 million Africans by 2020 and in Ghana, some financial instruments such as subsides, taxes, and duty waiver/reduction have been used but to a limited extent.

From an academic standpoint, several studies support the idea of renewable energy use, especially in the Telecom industry (Bull, 2001; Deichmann, Meisner, Murray, & Wheeler, 2010). These studies articulate the significance of energy efficiency and direct and indirect economic cost/benefits in modern and future telecommunication networks (Bull, 2001; Deichmann, Meisner, Murray, & Wheeler, 2010). Some other studies have been implemented in terms of advocacy and awareness creation of the importance and benefits of renewable energy in relation to protecting the environment and enhancement of development (Al-Badi, 2011; Anderson, 2009; Bindner, 2004; Deichmann, Meisner, Murray & Wheeler, 2010; Greenemeier, 2010; Menegaki, 2011). As part of the initiatives, a number of conferences, exhibitions and seminars are being held to promote sustainable energy as well as draw the public attention about issues pertaining to global warming. Notably among these programs are: the 2010 Canadian Utility Telecom Conference Program, the Green ICT conference in Aalborg University-Copenhagen, the Global Green Telecom Summit 2009 and the Kyoto Protocol. Other programs are organized by the ITU and Union of Concerned Scientists which show gains and formulate strategies to be achieved within set targets (Andersen, 2009; Copenhagen, 2009; Climate Conference, 2009; OECD, 2009; Richardson, 2009; unfccc.int, Kyoto protocol, 2010; Union of Concerned Scientists, 2007; www.idate.com, 2009).

Chapter 3: ICT and Electricity Scenario in Ghana

3.1 Introduction

Electrical energy has been a highly influential indicator of economic growth in every nation. Every country is endowed with different forms and levels of energy resources and therefore, has some influence on the development of their own energy sector. For decades, the use of electricity secures a steady flow of goods and services by transforming natural resources as well as enabling the production of goods (Organization for Economic Co-operation and Development/International Energy Agency, 2010).

Chapter three of our study examines Telecom/ICT development, Electricity generation and its impact on the development of Ghana. This involves the consideration of the geographical location of Ghana, its energy resources and Telecommunication/ICT development. In addition, this section provides a background to the various strategies to provide electricity in the country.

3.2 Overview of Ghana

Ghana is located in the western part of Sub-Saharan Africa. The country is boarded by Togo to the east, Cote d'Ivoire to the west, Burkina Faso to the north and the Gulf of Guinea to the south. (Figure 3.1). Ghana was created after World War II by merging the British Colony of the Gold Coast with Trans -Volta Togoland. Ghana then became the first Sub-Saharan African country in colonial Africa to gain independence in 1957. The total surface area of the county is 238,540km^2 and is divided into ten administrative regions, with the regions of Volta, Greater Accra and Brong Ahafo being the selected areas for this study (see Figure 5.4). The statistical data available indicates a progressive and steady growth in population since the time of its independence in 1957 from 6,726,815 to an estimated 24,658,823 in 2010 (see Table 3.1).

Date	Population	Growth Rate (%)
1960	6,726,815	N/A
1970	8,559,313	27.2
1984	12,296,081	43.7
2000	18,912,079	53.8
2010	24,658,823	30.4

Table 3. 1 Population Growth of Ghana

(Source: Ghana Population Census, 2010)

According to the 2010 census of Ghana, the Ashanti region is the most populous and also one of the developed regions while the Upper West region is the least populated region (see Table 3.2).

Region	Size (sq.m)	Population	% of Total	Population of Case Study Areas
Ashanti	24,389	4,780,380	19.4	
Greater Accra	3,245	4,010,054	16.3	130,795
Eastern	19,323	2,633,154	10.7	
Northern	70,384	2,310,983	10.1	
Western	23,921	2,376,021	9.6	
Brong Ahafo	39,557	2,317,292	9.4	81,000
Central	9,826	2,201,863	8.9	
Volta	20,570	2,118,252	8.6	200,000
Upper East	8,842	1,046,545	4.2	
Upper West	18,476	702,110	2.8	

Table 3. 2 Regional Population Distribution and Case Study Areas in Ghana

Source: Ghana Population Census, 2010)

3.3 Telecom/ICT Development in Ghana

Telecom and ICT development in Ghana has had its share of challenges due to poor basic infrastructure, unreliable electricity supply to support the technology and the poor unstructured management style of the Telecom authorities (Ghana Energy Commission, 2004). Since good governance heavily depend on the accessibility of quality and timely information to government agencies and the citizenry as a whole, it became necessary for the government of Ghana to open up a telecommunication industry. Until the liberalization of the Telecom industry, average Ghanaians never had access to fixed telephones except for the small privileged urban elites who had fixed telephone lines installed in their homes and offices (Addy-Nayo, 2001). The most suitable alternative to telecommunication has been face – to - face communication, sending verbal messages through intermediaries or through posting/sending letters. But in Ghana, sending letters takes days and travelling is cumbersome, time consuming and expensive. In response to this, the country took an important step of embracing liberalization/privatization that ended the monopoly of the government owned Ghana Post and Telecommunication Corporation (GPTC) which was responsible for operating the nation's telecommunication and licensing services (Haggarty, Shirley, & Wallsten, 2003) (Alhassan, 2003) (Addy-Nayo, 2001). The liberalization introduced competition that generated growth and innovation in the Telecom industry. This innovation permitted mobile Telecom network providers to operate in the country (Haggarty, Shirley, & Wallsten, 2003). Millicom Ghana Limited, the first mobile cellular Ghana network company, was granted the permission in 1990 to operate cellular communication and commenced operation in 1992. In 1994, the government embarked on an Accelerated Development Program (ADP) that established a five-year comprehensive restructuring through de-regularization of the country's telecommunication industry (Alhassan, 2003) (Addy-Nayo, 2001). The objectives of this program were to:

a) Increasing telephone density between 1.5 and 2.5 lines per 100 people.

b) Improving public access to telephone in rural and urban areas, through the installation of public payphone facilities.

c) Expand the coverage of the then mobile services.

d) Promote Ghanaian ownership and control of telecommunications companies.

e) Create an agency such as the National Communications Authority (NCA) from the public regulatory control (Alhassan, 2003) (Addy-Nayo, 2001).

To achieve these objectives, the ADP authorized the operation of Ghana Telecom and a new independent operator. They also recommended for financial support, a provision which aimed at promoting investment in new telecommunication infrastructure across the entire country as well as the privatization of Ghana Telecom (Alhassan, 2003) (Addy-Nayo, 2001). The ADP saw Telecom Malaysia buy a 30% share of Ghana Telecom for U.S. $38 million with full management control during the initial privatization.

Also, a consortium of the African Communication Group led by Western Wireless Company (WESTEL, USA) and the Ghana National Petroleum Company (GNPC) became the second network operator. Around 1996, the Telecom penetration was 0.03%, which illustrates that there were only three telephone lines per thousand people. During this time, the privatization introduced activities beyond what was being undertaken by the Ghana Posts and Telecommunications Corporation by increasing network coverage, implementing value-added Telecom services and increasing the subscribers' access to terminal equipment (Alhassan, 2003) (Addy-Nayo, 2001). By the end of the year 2000, the number of telephones lines increased remarkably, especially mobile phones. The mobile subscribers were a little over 90,000 which corresponds to 0.5%. Internet service provision also improved significantly with the authorization of over 140 Internet protocol service providers. For example, a number of companies were authorized to establish data networks using very small aperture terminals (VSATs) and/or frequencies to provide fixed and wireless broadband services to their clients such as the banks and mining companies (National Communication Authority, Ghana, 2009).

In 2002, the government of Ghana pursued an ICT-driven socio-economic development policy. This ICT policy was intended to transform Ghana into an information-rich, knowledge- based, technology-driven and high-income economy and society as quickly as possible (National Communication Authority, Ghana, 2009). In 2005, the National Telecom Policy was enacted to increase telephone penetration to 25% by 2010. In 2006, the country recorded about 5 million subscribers. By 2008, the mobile subscription soared beyond 11.5 million subscribers which translates to approximately 51.8% (National Communication Authority, Ghana, 2009). By 2010, the subscriber rate rose to 74%, almost three times the set target by the national Telecom policy (see Table 3.3). In relation to the mobile market, the fixed line market growth differed (see Table 3.3). At the end of 2002, fixed line subscribers numbered about 270,100 which corresponded to 3.4% penetration of the total population. The Telecom market saw a steady growth in 2002 from 653,100 to 11,714,300 by the end of 2008 when the entire coverage area of the mobile cellular signal was about 33 percent of the country (National Communication Authority, Ghana, 2009). Table 3.3 shows the details of telecommunication usage in Ghana.

	2002	2003	2004	2005	2006	2007	2008
Fixed Lines	270,100	292,400	307,400	345,700	360,300	386,100	143,900
Mobile Lines	383,000	775,000	1,051,000	2,990,000	5,208,000	7,604,000	11,570,430
Total Access Lines	653,100	1,067,400	1,358,400	3,335,700	5,568,300	7,990,100	11,714,300
Population	18,911,000	19,384,000	19,869,000	20,365,000	21,500,000	21,396000	22,348,000
	Penetration						
Fixed Line Penetration	1.4%	1.5%	1.6%	1.7%	1.7%	1.7%	0.6%
Mobile Penetration	2%	4%	5.4%	14.9%	24.2%	35.5%	51.8%
Total penetration	3.4%	5.5%	7%	16.6%	25.9%	37.2%	52.4%

Table 3. 3 Telephone Subscription in Ghana between 2002 and 2008

Source: National Communication Authority, 2009

Facility	No.	%	Western	Central	GT. Accra	Volta	Eastern	Ashanti	BA	Northern	UE	UW
Household with Fixed Lines	127,694	2.3	11,574	7,595	52,276	6,141	9,249	27,809	4,896	2,696	1,728	730
Household with Desktop/ Laptop	431,917	7.9	36,214	28,167	174,285	15,054	32,554	104,197	22,618	9,312	5,490	4,026
12Yrs + having internet	1,312,9171	7.8	103,166	104,301	555,847	50,644	88,869	295,251	52,923	32,128	15,777	13,065
12Yrs + having Mobile phones	8,049,408	47.7	750,227	669,083	2,191,910	540,623	806,291	1,859,656	622,715	341,536	167,421	99,946

Table 3. 4 Telecommunication Indicators persons 12 years and older

Source: Ghana Population Census, 2010

3.4 Telecom/ICT Industry in Developing Countries

3.4.1 Telecommunication Infrastructure in Ghana

Telecommunications services available in Ghana currently is comprised of a fixed line telephony network, mobile cellular, paging, data and other value added services. The infrastructure includes international connectivity via a SAT-3 submarine fiber optic cable, four international gateways via satellite and a Glo's submarine cable (National Communication Authority, Ghana, 2009). There is also 800 km of fiber optic backbone throughout parts of the country. Due to expansion, this fiber optic backbone project is anticipated to connect 23 sites and thus covering 4000km of the country. Six cellular Telecom operators and 35 operational Internet service providers are currently operating. In addition, there are 130 installed VSATs, 128 frequency modulation (FM) broadcasting stations, 12 television stations (6 are free on air) and two fixed line Telecom operators functioning in the country.

3.4.2 ICT in Developing Countries' Economies

Many developing countries are unable to enjoy the full benefit of ICT since the technologies strive on well-developed infrastructures and a considerable amount of high value added industries. The current contribution of ICT to all sectors of developing countries is insignificant. But these contributions could be higher if the technologies can be accessed at a relatively affordable price to the majority in both rural and urban centers. Thus, developing countries should consider using ICT as a catalyst to enable an economic change from an over-dependence on material extraction and peasant agricultural practices (Avgerous, 2008).

Some studies show that ICT use in some sectors of developing countries can improve economic growth, business growth, education, health care, good governance, social well-being, agriculture and poverty alleviation by providing cheaper, quality and empowered communication to the marginalized communities (Kuppusamy, Raman, & Lee, 2009; Leblois, 2011; Meng & Li, 2002). This ICT use can therefore improve human development and positively impact other economies.

3.4.3 Initiatives for ICT Growth in Africa

Like with many other innovations, many African countries are apprehensive about the sustainability of ICT, a factor that has not helped most of the previous developmental projects. However, there has been growing interest among governments and private sector partners about the need to broaden participation in the use of information in Africa. Some African governments, in conjunction with some international institutions (e.g. UNESCO, UNDP, ITU), have initiated discussions which have enabled the massive implementation of mobile phones with the aim of bridging the information gap (Okpaku J. , 2002). For example, the New Partnership for Africa Development (NEPAD) is focused on the strategy of ICT development in Africa through the support of the G8 Industrial Countries (Okpaku, 2002). The African Union with the participation of some partners have also initiated studies to harmonize policies and regulatory frameworks of Telecommunication and ICT as part of its strategy of "connecting Africa" and "Bridging the Digital Divide" in an effort to develop Telecom and ICT in Africa (African Union, 2008).

3.5 Electricity Generation in Ghana

Electricity generation in Ghana comes from two main sources: hydroelectric and thermal power plants (see Table 3.5). Figure 3.1 shows detailed power distribution network in Ghana.

3.5.1 Details of Generating Capacities

There are two hydroelectric power plants in Ghana. One at Akosombo and the other at Kpong with a capacity of 1,023MW and 160MW, respectively. There are a total of five thermal power plants in Ghana. These are the Takoradi thermal power plant-T1 (TAPCO), the Takoradi thermal power plant-T2 (TICO) and Mines reserve plant (MRP) all located in Takoradi in the Western region of Ghana. The other two plants are Tema thermal power plant-T1 (TT1PP) and Tema thermal power plant (TT2PP) are located in the Greater Accra region of Ghana. TAPCO has a capacity of 364MW, TICO 241MW, MRP 50MW, TT1PP 113MW and TT2PP 80MW.

Power Plants	Owner/Operator	Installed Capacities (MW)	Maximum Capacity (MW)	% of Existing Capacity
Akosombo Hydroelectric Plant	Volta River Authority	1,023	1,020	52.7 %
Kpong Hydroelectric Plant	Volta River Authority	160	152	7.9 %
Takoradi Thermal Power Plant- T1 (TAPCO)	Volta River Authority	364	330	17 %
Takoradi Thermal Power Plant- T2 (TICO)	Volta River Authority	241	220	11.4 %
Takoradi Thermal Power Plant- T1 (TT1PP)	Volta River Authority	113	113	5.8 %
Mines Reserve Plant	Volta River Authority	80	50	2.6 %
Tema Thermal Power Plant- T2 (TT2PP)	Volta River Authority	50	50	2.6 %

Source: GRIDCo, 2010

Table 3. 5 Electricity Generation in Ghana

Source: GRIDCo, 2010

Figure 3. 1 Map of Ghana Showing Electricity Distributions

(Source: GRIDCO, 2010)

3.5.2 Background to Power Generation in Ghana

The idea of constructing a hydroelectric dam across the Volta River to turn Ghana's bauxite into aluminum came from the geologist, Albert Kitson, from the colonial Gold Coast government (Faber, 1990). In 1961, the Ghana government initiated the Volta River Project to be built in Akosombo. By 1965, four hydroelectric generating units with a combined capacity of 588MW were installed. In addition, two units with a combined capacity of 324MW were installed in 1972, bringing the total capacity to 912MW. In 1981, a second hydroelectric plant with 160MW capacity was installed in Kpong. Both hydroelectric plants have a long term capacity of approximately 4,800GWh/year (Yankah, 1999). Between 1982 and 1983, a severe drought hit Ghana causing the water level in the Akosombo dam to decrease. This drought led to a power crisis which necessitated the creation of the National Energy Board. This board planned a comprehensive development and utilization of energy resources, specifically to promote the use of renewable energy. In 1987, the demand for electricity increased primarily due to population growth, urbanization, economic growth and rural electrification (Yankah, 1999). The national electricity grid was extended beyond the Ashanti region, thus to Brong Ahafo and the three Northern Regions (i.e. Northern, Upper East and Upper West). At the same time, Self-Help electrification projects were initiated to assist the rural communities in generating their own power. In 1988, only 28% of the population had access to the national grid electricity (Yankah, 1999). With an increasing demand for electricity, an old diesel generator with a 30MW capacity was rehabilitated in 1990, thereby increasing the total generating capacity of the country to 1,082MW. Subsequently, light crude oil thermal plants were introduced in sequence (see Table 3,5). Due to these modifications, 43.7% of the population had access by 2000 (Ghana Energy Commission, 2004), 50% by 2005 (Obeng, Kemausuor, & Brew-Hammond, 2009), 55% by 2008 (World Bank, 2007) and 72% by 2010 (Power System Energy Consulting, 2010). This increase in citizen access to grid electricity has made Ghana third highest in Sub-Saharan Africa, after Mauritius and South Africa.

3.5.3 Renewable Energy Resources in Ghana

The country's renewable energy resources, such as solar, wind, small hydro and bioenergy, are potential resources for modern electric power generation (Ministry of Energy, 2006). Though solar energy is abundant in the country, it is generally utilized in its natural state through direct access such as drying, farming, tanning, daylight, heating etc. Solar energy is used by few households for electricity generation. In addition, wind and small hydroelectric systems are also good sources that are ideal in certain parts of the country, but are yet to be utilized in the national energy mix (Ministry of Energy, 2006).

3.5.3.1 Solar Energy

Since Ghana is located in the tropics, solar radiation of $4kWh/m^2/day$ to $6.5kWh/m^2/day$ is readily available throughout the year with an annual average duration of sunshine between 1800hrs to 3000hrs (4.5 to 8 hour/day) (Ministry of Energy, 2006) (Tables 3.6-3.8; Figure 3.2).

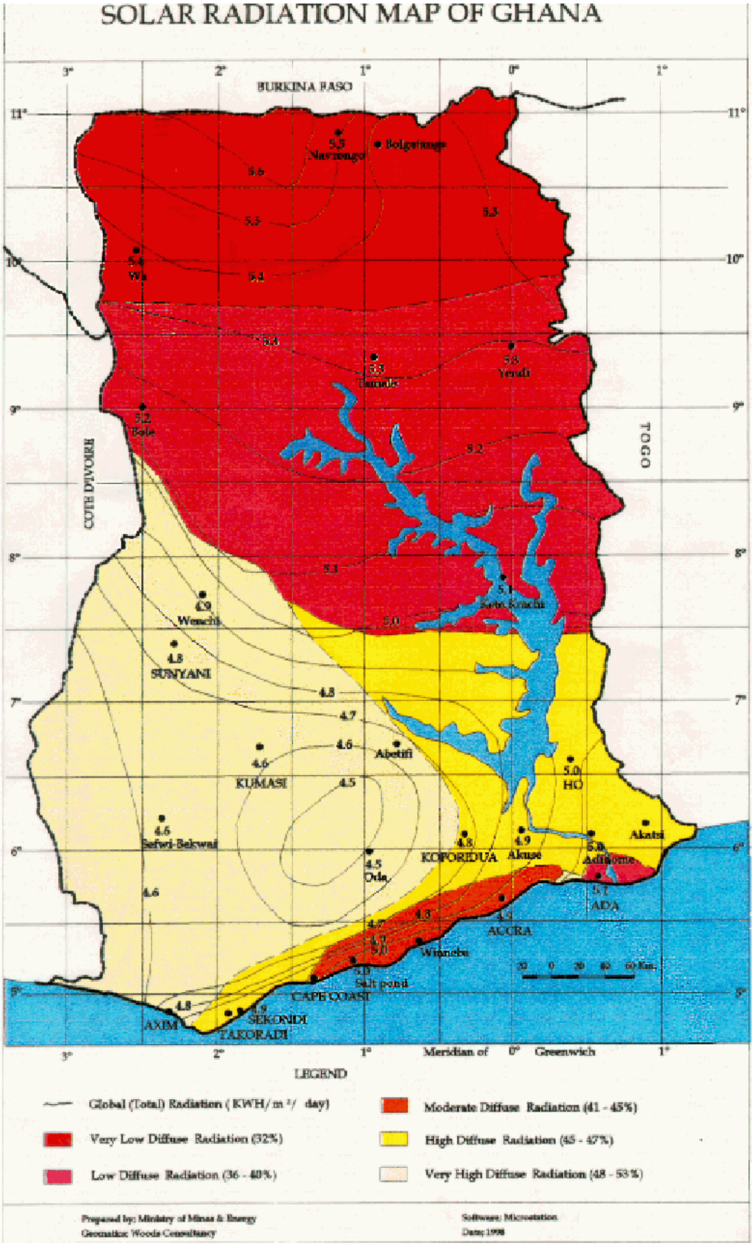


Figure 3. 2 Solar Radiation Map of Ghana

Source: Energy Centre (KNUST)

Mon/ Town	1	2	3	4	5	6	7
JAN.	5.391	5.124	5.156	5.422	5.107	5.464	5.193
FEB.	5.400	5.479	5.462	5.821	5.414	5.089	5.495
MAR	5.783	5.613	5.558	5.762	5.679	5.798	5.483
APRIL	5.958	5.890	5.862	5.797	5.968	5.859	5.711
MAY	5.934	5.869	5.919	5.710	5.859	5.873	5.507
JUNE	5.719	5.510	5.415	5.091	5.188	5.611	4.972
JULY	5.339	4.954	5.044	4.645	4.684	5.135	4.356
AUG.	5.098	4.841	4.629	4.494	4.531	4.937	4.120
SEPT.	5.324	5.004	4.957	4.827	4.771	5.125	4.405
OCT.	5.677	5.472	5.623	5.540	5.347	5.641	4.927
NOV.	5.616	5.695	5.674	5.520	5.650	5.649	5.127
DEC.	4.824	5.213	5.165	5.251	5.121	5.074	4.905
AVE.	5.505	5.389	5.372	5.323	5.277	5.122	5.017

(Towns: 1= Navrongo, 2 = Tamale, 3 = Yendi, 4 = Bole, 5 = Kete- Krachi, 6= Wa, 7 = Wenchi)

Table 3. 6 10-Year Monthly Average of Solar Irradiation (kWh/m2/day) in 7 Synoptic Stations in the Northern sector of Ghana (Source: Department of Mechanical Engineering – KNUST)

Mon./Town	1	2	3	4	5	6
JAN	4.818	4.695	5.032	4.711	4.505	4.872
FEB	5.313	5.084	5.525	5.139	4.771	5.224
MAR	5.305	5.265	5.558	5.260	4.884	5.509
APR	5.356	5.495	5.580	5.434	5.176	5.716
MAY	4.709	5.311	5.406	5.287	4.896	5.576
JUN	4.029	4.559	4.824	4.641	4.303	4.916
JUL	4.036	4.114	4.752	4.074	4.015	4.601
AUG	3.783	3.753	4.602	3.842	3.802	4.187
SEP	3.992	4.069	4.682	4.437	4.240	4.663
OCT	4.707	4.954	5.243	5.174	4.783	5.500
NOV	5.000	5.007	5.559	5.241	4.931	5.624
DEC	4.552	4.446	5.072	4.857	4.501	5.074
AVERAGE	4.633	4.729	5.153	4.841	4.567	5.122

(Towns: 1= Kumasi, 2 = Bekwai, 3 = Abetifi, 4 = Koforidua, 5 = Akim Oda, 6= Ho)

Table 3. 7 10-Year Monthly Average of Solar Irradiation (kWh/m2/day) in 6 Synoptic Stations along the Forest Zone of Ghana (Source: Department of Mechanical Engineering – KNUST)

Mon/Town	1	2	3	4	5	6
JAN	4.660	4.882	4.995	4.790	4.899	4.634
FEB	5.206	5.399	5.381	5.376	5.555	5.056
MAR	5.256	5.569	5.649	5.463	5.486	5.247
APR	5.665	5.605	5.937	5.663	5.684	4.951
MAY	5.416	5.051	5.570	5.227	5.354	5.281
JUN	4.613	3.936	4.978	4.361	4.440	4.591
JUL	4.189	4.242	5.064	4.384	4.670	4.304
AUG	4.527	4.230	5.065	4.227	4.482	4.108
SEP	5.107	4.382	5.510	4.589	4.997	4.727
OCT	5.623	5.178	5.872	5.518	5.678	5.297
NOV	5.510	5.466	5.480	5.553	5.692	4.766
DEC	4.930	4.986	5.359	4.975	5.153	4.810
AVE.	5.059	4.911	5.409	5.011	5.174	4.814

(Towns: 1= Accra, 2 = Axim, 3 = Ada, 4 = Takoradi, 5 = Saltpond, 6= Akuse)

Table 3. 8 10-Year Monthly Average of Solar Irradiation (kWh/m2/day) in 5 Synoptic Stations along the Coast of Ghana (Source: Department of Mechanical Engineering – KNUST)

The data on solar radiation across the country indicates that geographical variation exists, with the highest solar intensity in the northern sector and the lowest in the middle of the country (see Table 3.6-3.8; Figure 3.2). Over the years, the attraction of a solar PV system has increased significantly, especially now that the country is experiencing energy crises. The country estimates that the installation of 335 more solar PV systems could generate about 160 peak kilowatts of power (Obeng G. Y., 2008). According to the Ghana Statistical Service (2012), about 0.2% of the national energy mix comes from solar energy. Apart from the pilot grid, 50kWp solar PV systems installed at the Ministry of Energy, the 4kWp solar PV system at the Energy Commission and the 4kWp solar PV system at KNUST College of Engineering for demonstration purposes, there are some scattered stand-alone off-grid systems that have been installed in different parts of the country. Though solar PV systems are cost-effective, especially for low voltage application, the initial cost of the system is high and the lack of pre-financing is impeding access (Sawin, 2004).

3.5.3.2 Wind Energy Resource

Wind energy potential assessment studies, that have been conducted in several areas in Ghana indicate that the coastal belt of the country has good wind energy potential and may be capable of generating about 50MW of electric power (Ghana Energy Commission, 2006). The best surface data for wind assessment were obtained from 11 measurement stations identified along the coastline of Ghana, including the towns along the coast in the greater Accra region (e.g. Tema, Ada-foah, Lolonya, Petu and Kpone). Other research studies along the meridian through Ada to the Volta region have been conducted for the purpose of large-scale grid power generation and there are indications of the existence of relatively strong winds that could be utilized for power generation (Ghana Energy Commission, 2006) (Park, Schafer, & S, 2008). The average monthly wind speed at 12m is between 4.8 to 5.5m/s. The computed satellite ocean wind measurement also shows that the wind speed at 50m is between 6.2 and 7.1m/s. There is also an excellent wind resource along the Ghana/Togo border at the speed of between 8.4 to 9m/s (Park, Schafer, & S, 2008). About 0.5% of Ghana has wind speed greater than 5m/s. This shows that Ghana has sufficient wind resources for power generation, since wind speeds greater than 4m/s are generally considered to have generation potential (see Table 3.9 & 3.10). On the east coast of the meridian, Lolonya has the highest wind speed of 5.43m/s. The predominant direction of the wind speed is 240˚ with a corresponding mean wind speed of 5.66m/s. Ada-foah has average wind speed of 5.33m/s in 240˚wind speed direction. The analyses of the available wind data suggest that the average wind speed for Mankoadze, Lolonya, Ada-foah, Petu and Apklaku are in the range of 5 to 6.1m/s at 12m. With these speeds, electric power generation is confined to the coastline and the most economical exploitation based on current technology is at 50m-elevation with average wind speeds between 6 and 6.3m/s (Park, Schafer, & S, 2008).

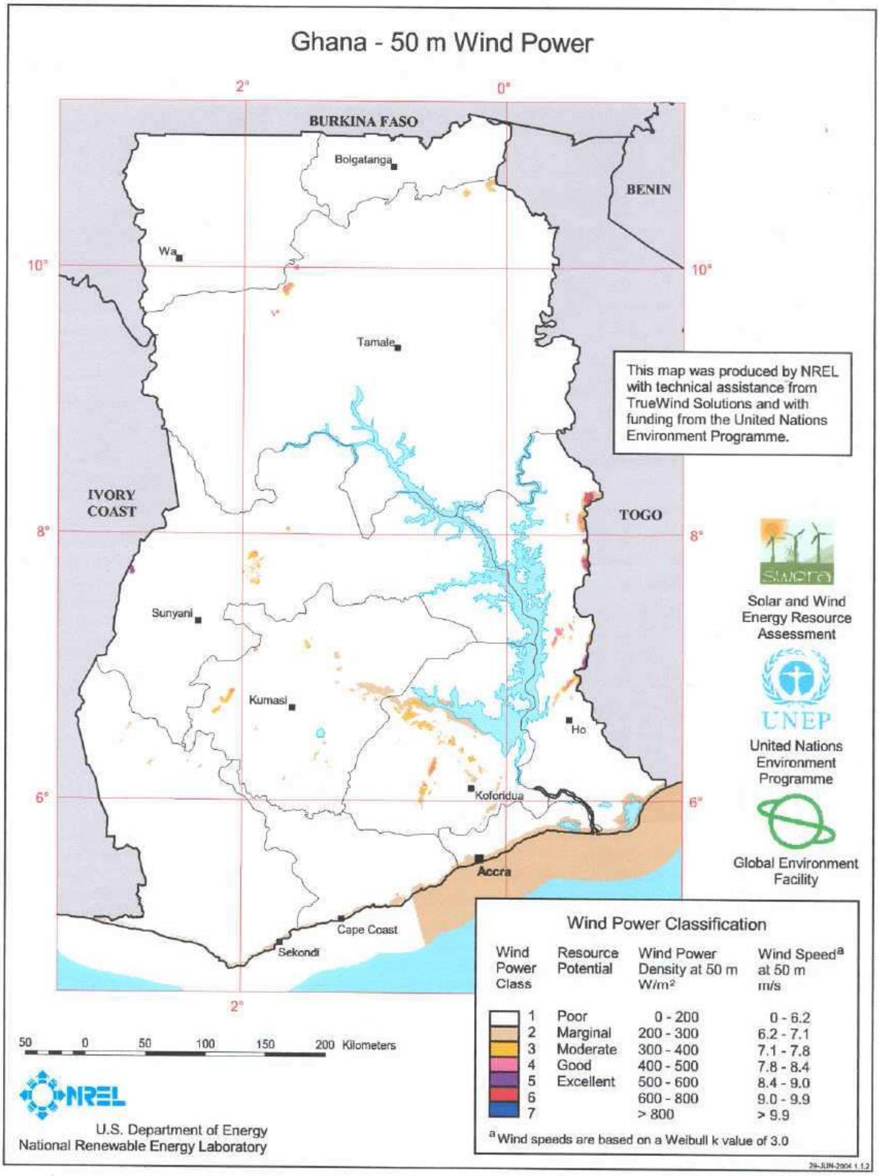


Figure 3. 3 Wind Potential of Ghana

Source: NREL, US Department of Energy

EXTRAPOLATED MONTHLY MEAN WIND SPEED (m/s) @ 12 m (1995 - 2002)

Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
Abetifi	3.9	4.4	4.7	4.5	4.2	4.4	4.7	4.6	4.2	4.0	4.0	3.7	**4.3**
Accra	3.3	3.8	4.0	4.0	3.5	3.7	4.6	4.9	5.0	4.2	3.4	3.1	**4.0**
Adafoah	4.6	5.5	5.6	5.2	4.7	4.7	4.9	4.9	5.7	5.7	5.2	4.7	**5.1**
Akatsi	2.6	2.9	2.9	2.8	2.5	2.5	3.3	3.5	3.3	2.6	2.2	2.6	**2.8**
Akim Oda	2.3	2.5	3.0	3.1	2.4	2.4	3.0	2.8	2.8	2.5	3.3	2.7	**2.7**
Akuse	3.5	4.1	4.4	4.4	3.7	3.5	4.1	4.3	4.0	3.4	3.0	3.2	**3.8**
Axim	2.9	3.4	3.6	3.4	3.2	3.5	3.5	3.4	3.5	3.6	3.3	3.1	**3.4**
Bekwai	2.0	2.2	2.3	2.2	2.1	2.0	2.1	2.2	2.2	2.1	2.1	2.0	**2.1**
Bole	3.3	3.5	3.7	3.6	3.2	2.9	3.0	2.6	2.1	2.3	2.6	3.1	**3.0**
Ho	2.5	2.7	2.8	2.7	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4	**2.5**
Koforidua	2.3	2.4	2.5	2.4	2.4	2.4	2.5	2.6	2.5	2.4	2.3	2.2	**2.4**
Krachi	2.8	3.4	3.7	3.6	3.2	2.8	2.8	2.6	2.5	3.0	2.6	2.5	**2.9**
Kumasi	3.2	3.8	4.2	4.0	3.7	3.7	4.4	4.3	4.1	3.6	3.4	3.2	**3.8**
Navorongo	3.6	3.7	3.1	3.2	3.2	2.9	2.8	2.8	2.6	2.7	2.8	3.3	**3.0**
Saltpond	3.6	4.3	4.2	3.9	3.7	3.7	3.9	4.2	4.5	4.2	3.8	3.5	**4.0**
Sunyani	3.5	3.9	4.4	4.2	3.8	3.9	4.1	4.1	3.7	3.5	3.4	3.4	**3.8**
Takoradi	3.5	3.9	4.4	4.4	3.9	4.1	4.2	4.6	4.9	4.4	4.0	3.3	**4.1**
Tamale	4.1	4.6	4.7	4.9	4.3	3.9	4.0	3.6	3.0	3.1	3.3	3.8	**3.9**
Tema	4.3	4.7	4.8	4.5	4.2	4.4	5.0	4.9	5.1	5.0	4.6	4.2	**4.6**
Wa	3.9	4.1	3.8	4.0	3.7	3.5	3.3	2.7	2.3	2.8	2.9	3.2	**3.3**
Wenchi	3.4	3.7	4.1	3.9	3.7	3.7	3.7	3.7	3.5	3.1	3.1	3.1	**3.6**
Yendi	2.9	3.2	3.0	3.2	3.0	2.8	2.8	2.7	2.4	2.4	2.3	2.7	**2.8**

Table 3. 9 Monthly Mean Wind Speed (m/s) at 12 m for 22 Synoptic Stations across the Country Source: Department of Mechanical Engineering – KNUST, 2009

Month/ Town	Apklaku	Mankoadze	Ada-Foah	Lolonya	Kpone
Jan.	5.0	4.7	5.1	5.1	4.4
Feb.	5.1	5.1	5.0	5.1	4.4
Mar.	5.7	5.5	5.8	5.9	5.3
April	5.9	5.1		5.8	5.1
May	4.8	4.5	4.9	5.1	4.9
June	5.0	4.9	5.6	5.6	4.5
July	5.8	5.2	5.3	5.5	5.2
Aug.	6.1	5.2	5.2	5.4	5.3
Sept.	6.0	5.5	5.7	6.4	5.4
Oct.	5.1	5.0	6.3	6.4	5.4
Nov.	4.7	4.8	5.0	5.1	4.6
Dec.	4.6	4.6	4.2	4.3	3.9

Table 3. 10 Wind Speed in Some Specific Towns along the Coast

Source: Department of Mechanical Engineering – KNUST, 2009

3.6 Initiatives towards Power Generation

The government of Ghana has commenced the construction of hydroelectric projects on a Build Operate Transfer financing scheme. This scheme is for the Bui hydroelectric project on Black Volta and Pra rivers. The Bui hydroelectric project is estimated at a cost of U.S. $700 million and is expected to generate a capacity of 400MW of electricity. It is anticipated that the power generated from the Bui hydroelectric project could be exported to Burkina Faso, Mali and La Cote d'Ivoire (Ivory Coast).

3.7 Conclusion

This chapter outlined the development of Telecom and energy sectors and their relationships. The chapter also reviewed the implementation interest of Ghana and activities program for development of ICT innovation. The chapter also described the geographical features of Ghana, the tropical climate with high temperatures during the greater part of the year with long durations of sunshine. Ghana has multiple energy sources such as solar, wind, biomass and hydro. The total installed electricity generation capacity currently is valued at 2,031MW which is derived mainly from hydro and thermal (e.g. light crude and diesel) power plants. The government is making efforts to provide ICT centers in each of the 230 districts across the country and to improve electricity supply.

Chapter 4: Theoretical Foundation

4.1 Introduction

The chapter presents the theoretical considerations relating to energy and telecommunication. These considerations focus on the possible dependency for Telecom to use or rely on sustainable energy generation which can enhance the Telecom industry in Ghana. It proposes a framework that could improve the electricity supply to the Telecom base transceiver stations. At the time of putting the theoretical framework together, we were encouraged by how Kaplan (1964), coined definition of theory. It states that, "A theory is a way of making sense of a disturbing situation". There have been different approaches as to how, what form and to what level of understanding can sustainable development be expressed. The ideology of capitalism or industrial ecology (Hawken et al., 1999) appears to offer an unproductive understanding of increasing energy resource productivity focusing on what can be achieved with technologies that depend on the existing resources. Some researchers have tried to conceptualize the use of renewable energy components that may reduce costs of energy in the future. For example, (Krumdieck, 2007) proposes that economics, engineering and science cannot independently manage the energy supply and environmental challenges by just focusing on renewable energy, efficient improvement or consumer behavior changes, rather through multidisciplinary approach.

Past research studies have described different models of technology application and diffusion, especially within the IT sector such as the Technology Acceptance (TAM; Davis, 1989) Model, the Diffusion of Innovation (DOI; E.M Rogers, 1962) Model, the Theory of Planned Behavior (TPB; Ajzen, 1991) and the Technology-Organization-Environment (TOE; Tornatzky & Fleischer, 1990) Framework. Several empirical studies have used the TOE framework with different technology innovations and different contexts to describe technology application discussions (Chang, Hwang et al., 2007; Dong et al., 2006; Huy, 2007; Kuan & Chau, 2001; Srivastava & Teo, 2006; Teo & Pan, 2004; Zhu, Dong et al., 2006; Zhu & Kraemer, 2005). A unifying feature of all the theories and models is that income is not solely considered as a factor of adoption. Out of the several conducted studies, there is little information regarding the integration of renewable energy and Telecom (ICT) innovations for development in Sub-Saharan Africa including Ghana.

Acknowledging the fact that businesses in developing countries are confronted by a lack of resource access, after reviewing the technology adoption/application models, TOE appears to be the most appropriate to support this study. It was also observed that the TOE framework has not been applied to technology application within the African context. Furthermore, based on TOE's strong theoretical foundation and the consistent empirical support presented in many research studies, the TOE framework is most appropriate and thus a suitable starting point for this study.

4.2 Technology-Organization-Environment (TOE)

According to the TOE framework, every organization needs to consider the technology, the organization and environmental factors in deciding whatever technology it adopts/implement (Tornatzky & Fleisher, 1990).

4.2.1 Technological Context

Within the technological context, both internal and external technologies that are relevant to the organization are described (Chau & Tam, 1997) (Srivastava & Teo, 2006) (Zhu & Kraemer, 2005). The technology in this sense refers to current practices, the existing technologies and equipment being used within the organization, as well as all other technologies that are available in the market outside the organization that could be used for effective functional business processes (Hage, 1980; Starbuck, 1976; Thompson, 1967). Past studies considered direct benefits that can be derived from technological innovation as a determining factor for technological application. This perception is similar to relative advantage theory which refers to the extent at which technology is providing benefits to the organization (Chau & Tam, 1997; Kuan & Chau, 2001; Mehrtens, Cragg et al., 2001; Wang, Chang et al., 2004). Organizations that realize the benefits associated with a particular technology are more likely to implement it (Raach & Hippel, 2013). Recent studies identified image improvement, enhanced customer service and competitiveness as some of the benefits (Kuan & Chau, 2001). Perceived benefits were found to be significant among firms that adopted and applied new technologies. However, firms that are reluctant in applying new technologies report little to no performance improvement (Kuan & Chau, 2001).

While firms may be motivated to use technologies due to the benefits, successful technological implementation requires some level of expertise in the technology and readiness of the organization (Kuan & Chau, 2001) (Raach & Hippel, 2013). Whenever leaders in organizations realize an obstacle in new technological implementation, they are generally reluctant to proceed with the application process (Hong & Zhu, 2006). (Kapurubandara, 2009) suggests that for the successful adoption of new technologies in an organization, the perceived barriers should be addressed. Other researchers also acknowledge that perceived barriers could delay the implementation of such technologies until they are able to obtain the right resources (Kuan & Chau, 2001).

4.2.2 Organizational Context

The organizational context describes the organizational structure, such as the size of the organization and internal control measure (e.g. centralization, formalization and complexity of its managerial structure), that involves the quality of its human resources and the amount of excess resources available within the organization (Zhu & Kraemer, 2005).

4.2.3 Environmental Context

The environmental context is the area in which the organization interacts with its competitors, the regulatory agencies, governments and other stakeholders (Tornatzky & Fleischer, 1990). Previous studies have highlighted the importance of industry, competition, regulation and relationship with the government as environmental factors on decisions based on technology adoption (Zhu & Kraemer, 2005). Within the ICT industry, the adoption of the Internet has enabled most organizations to identify good suppliers and acquired new methods of purchasing supplies regardless of geographic location (Gruber & Koutroumpis, 2010). Firms that have previously used ICT for their businesses have improved by gaining cost-effective supplies and have reduced their turnaround time to get their products or services to business (Kuan & Chau, 2001).

Previous studies have also provided evidence that suppliers can influence an organization's interest in adopting certain technologies in order to maintain their business relationship more effectively with them (Chong, 2004). Technological application within the firm may encourage suppliers to take advantage of these new opportunities to improve and expand their supply businesses. Since ICT and renewable energy technologies open new markets for sourcing suppliers, business partners and customers, more companies are utilizing this network to engage in the value chain activities (Chong, 2004). The three contexts of TOE framework are expected to interact cohesively to influence technological adoption within an organization. The framework has a solid theoretical basis, consistent empirical support and the potential of application to IS innovation domains. The framework encourages researchers to consider innovation in a broader context of technological adoption. Many researchers used the TOE framework to understand adoption of IT in different services, such as website development (Oliveira & Martins, 2011) and electronic data interchange (Kuan & Chau, 2001). The TOE framework has also been used for studying the adoption and assimilation of different types of IT innovation and it serves as a useful analytical framework in electronic data interchange (Kuan & Chau, 2001) (Zhu & Kraemer, 2005) (Zhu, Kraemer, & Xu, 2003).

With increased implementation, it is evident that TOE does not have a clear description of factors that influence the organizational adoption decision. TOE framework is consistent with the DOI theory, in which (Rogers, 1995) stressed on the individual characteristics and particularly on both the internal and external characteristics of the organization as drivers for organizational innovativeness. Though similar to the technology and organization context of the TOE framework, TOE framework has included environmental context (Figure 4.1). The environment context presents both opportunities and challenges for technological innovations. The TOE framework makes Rogers' innovation diffusion theory better by explaining the diffusion that takes place within the firm itself (Rogers, 1995).

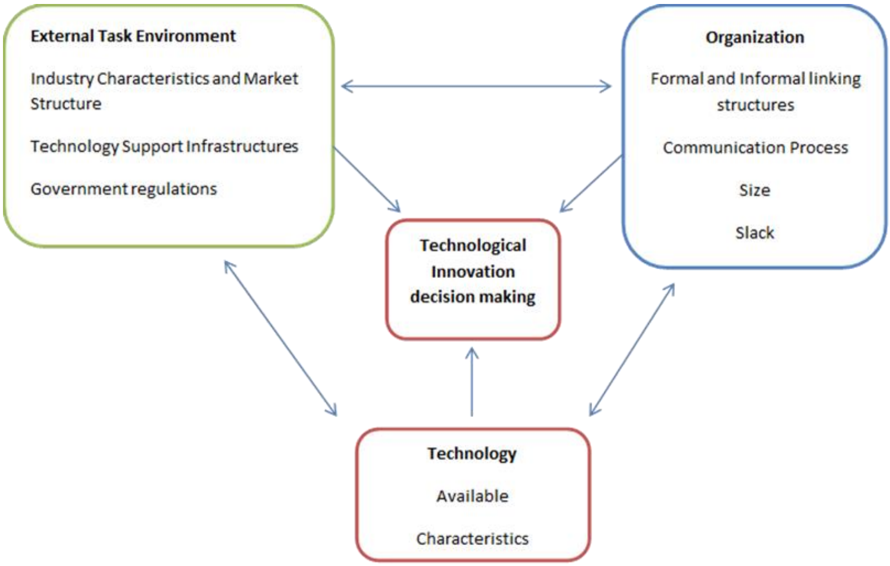


Figure 4. 1 Technology, Organization, and Environment (TOE) Framework (Tornatzky & Fleischer, 1990).

4.3 Conclusion

TOE theoretical approach has been fundamental in the formation of this study. This theoretical approach has been chosen in order to make the study applicable in context of developing countries. Whilst the theory has been applied to analysis of development diffusion processes of a variety of artefacts in the developed nations, it has rarely been used to study technological development application in developing countries.

The role played by the different stakeholders within Telecom and energy sectors relates to their environmental context and this study reveals the importance of the different assessment of acceptance of renewable energy. As the study shows, the stakeholders all influenced the different perceptions of applying renewable energy (Solar PV and wind energy) at the BTS. TOE is specific about technology development, but it can be enhanced through the explicit discussion with organizations and individuals concerned with a particular innovation. This of course involves the examination of resource capacity and existing social structures as well as analyzing how stakeholders influence the acceptance of an innovation.

Chapter 5: Research Methodology

5.1 Introduction

The methodology used in this study relies on an exploratory-based survey research design. This chosen methodology was considered appropriate for this study as the renewable energy industry is an emerging field and the study aims at analyzing variable issues relating to unreliable, unstable, poor power supply within Jema in the Brong Ahafo region, Ho in Volta region and Ada–Foah in the Greater Accra region of Ghana. The completed research was designed to use both interviews and surveys to gather both qualitative and quantitative data and relies on research methods for solar and wind power scenarios simulations, including the application of techno-economic evaluation and output analysis. This combined approach reveals the validity of factors that have been identified as inhibiting the effective development of the Telecom and ICT industry in Ghana.

Through the use of descriptive and exploratory approaches (Gall, Gall, & Borg, 2003), this chapter also provides a discussion of the overarching philosophical approach adopted in this research design, which justify both the employed methodological choices and reasoning. Such choices and reasoning allowed not only an exploration of the development of ICT and its impact on rural societies but also the effect of electrical power generation from unreliable and unstable sources on the environment in the three primary selected study sites.

This study commenced with a brief description of philosophical research assumptions underpinning this research, followed by an outline of the important characteristics of research philosophies drawing from either an interpretive or positivist stance. The chapter also describes the research design which incorporates the rationale for the selection of study sites, organizations, as well as other sources of data collection and the analytical techniques or processes. Furthermore, the justifications for all the choices under the design parameters are outlined in relation to the research objectives and the adopted philosophical approach.

5.2 Research Philosophy

The term philosophy in research is an expression used to describe how a researcher thinks, the viewpoints of what is perceived to be the realistic ways of life and the approach adopted in the development of knowledge as well as the chosen route in the realization of a study project (Saunders, Lewis, & Thornhill, 2007). However, researchers in the field disagree about the order, the name and nature of research stages, which presents a challenge in understanding research design. (Crotty, 1998) classified research into four stages: epistemology, theoretical perspective and methodology (Figure 5.1). Alternatively, (Saunders et. al., 2007) developed a six-stage model: philosophies, approaches, strategies, choices, time horizon and techniques and procedures (Figure 5.2). (Saunders et al., 2007) disagree with (Crotty, 1998) arrangement of the stages in research and furthermore, combined 'epistemology' with 'theoretical perspective' and classified them as philosophy to create what is known as "the research onion".

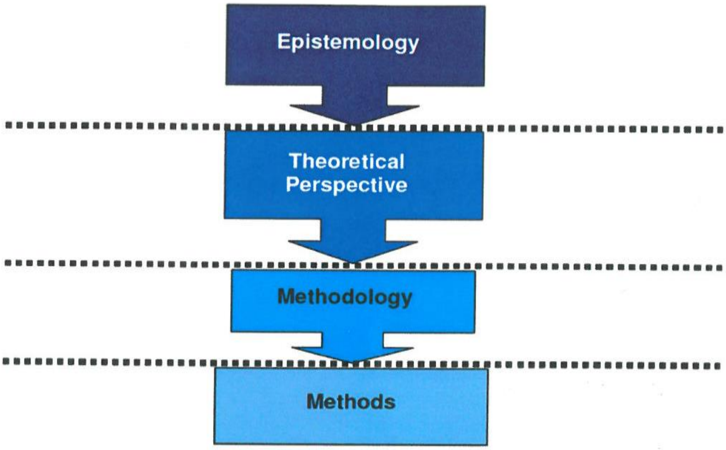


Figure 5. 1 Model of research stages (Crotty, 1998).

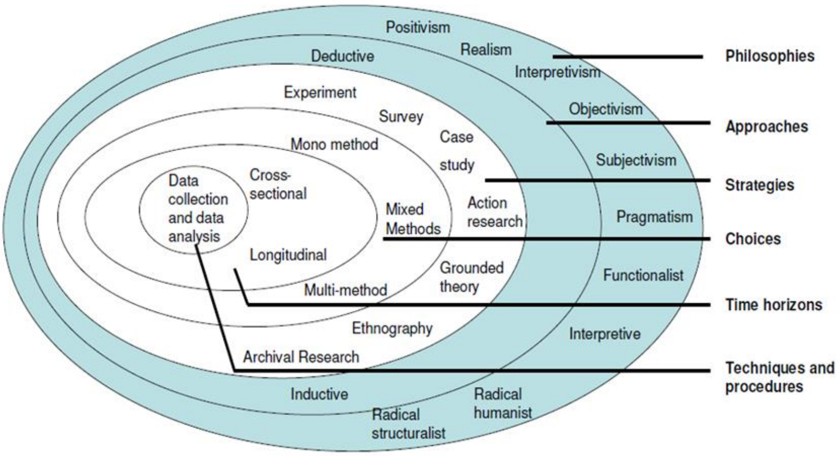


Figure 5. 2 The 'research onion' (Saunders, Lewis, & Thornhill, 2007).

Different types of research philosophies such as pragmatism, realism etc. are available to researchers to manage assumptions, beliefs and the interpretation of data. These different types are illustrated in Sounder's diagram (Figure 5.2). Collis & Hussey (2009) suggested that positivism and interpretivism are the two main research paradigms. Though the two paradigms are supported by different hypotheses, it may be useful to bring the two ideas together to work simultaneously so the characteristics and beliefs of each paradigm complement each other. Both paradigms play a vital role in research and the use of each is complementary (Collins & Hussey, 2009). Since the main purpose of studying science is to make our perception of the world clear through empirical evidence that add up to the existing knowledge and truth of science, the philosophical assumption underlying this complete research is pragmatism a blend of positivism and interpretivism reliant upon both qualitative and quantitative methods of analysis in the study. In order to describe the existing relationship between Telecom/ICT and energy consumption in Ghana, the research conducted considered these two main research philosophies of scientific investigation: both positivism and interpretivism.

5.3 Research Design

The research design explores the application of renewable energy (i.e. solar PV and wind) at the Telecom base stations in Ghana and other developing countries. In order to respond to the research questions (How can renewable energy application enhance Telecom/ICT operation in Ghana?, What are the critical factors influencing sustainable development of telecommunication and ICT use in Ghana?, How does the unreliable supply of electricity affect the operations of the mobile telecom operators?, How would a framework be modeled to incorporate the challenges hindering sustainable ICT application?, Can renewable energy provide reliable electricity for the base transceiver stations in Ghana? and What will be the financial benefit/cost of renewable energy to the Telecom operator?), it is necessary to understand how unstable electricity supply to the Telecom industry is affecting its widespread applicability and development. In order to achieve our research objectives, the study was divided into four stages. The first stage identified factors that may detract from ICT development in Ghana. These factors were then categorized accordingly as “major and minor factors.” The major factors are: unstable electricity supply, poor Telecom infrastructure and policy or regulatory frameworks. The minor factors are: Telecom market regulation and education (e.g. basic education and ICT knowledge). The second stage was achieved through field interviews of key representatives in Ghana: mobile Telecom operators, Telecom stakeholders and energy stakeholders. These interviews explored major and minor factors influence in the development (or lack of it) of Telecom and ICT. The third stage relied on simulations to confirm, or otherwise understand, the technical feasibility and economic benefit of renewable energy. The fourth and final stage is framed by the analysis of data.

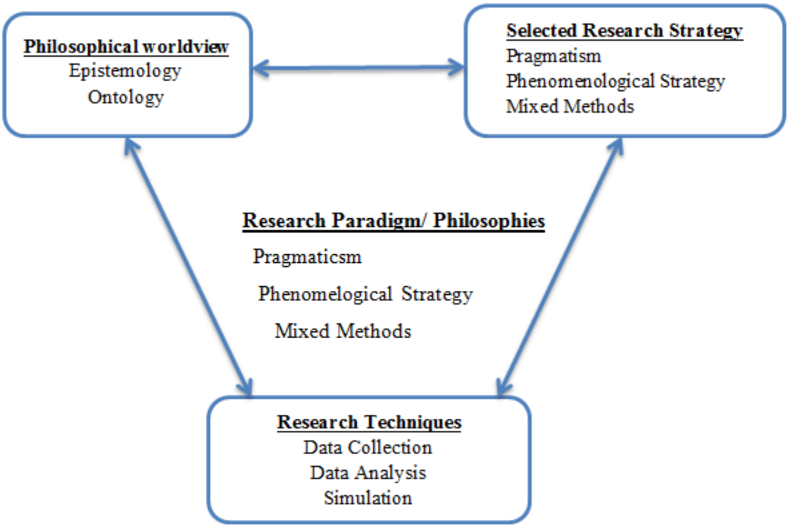


Figure 5. 3 Framework for Research Design Adapted from (Creswell, 2009)

5.4 Research Approach

The research approach focuses on the various sets of procedures and techniques adopted in the data collection and analysis process. The study adopted a mixed methods approach in order to bring together the respective strengths of quantitative and qualitative methods in answering the research questions.

5.4.1 Quantitative Methods

Simple closed-ended questions were used to gather quantitative responses from sixty opinion leader and assembly men/women and about forty eight questionnaires were collected. The office of the District Chief Executives (the administrative head of the district) were involved in the distribution of the questionnaire to attract development to the districts of the selected sites. Additionally, due to frequent complaints of diesel fuel theft, law enforcement officers were included in the questionnaire distribution. The rationale for developing the questionnaire was to solicit stakeholders view on activities of the Telecom companies.

5.4.2 Qualitative Methods

The researcher conducted a one - on - one interviews with the representatives of the mobile Telecom operators, stakeholders in the Telecom and Energy sectors as well as the solar companies. Interviewed representatives were nominated by their respective organizations following an official request through letters that were submitted to their organizations. Because only twenty one interviews were conducted out of the proposed thirty, the number of interviewees were small, the researcher arranged meetings for each and every person. To identify salient features across organizations, sets of unstructured or semi-structured open - ended questions were asked. In this way, the qualitative results allowed a better understanding of common challenges in the Telecom and energy sectors. The researcher also used recordings during the interview to capture responses for subsequent review. The use of devices, such as tape recorders and cameras, in qualitative research was recommended by some researchers as they boost the quality of research (Bade, 2011), (Silverman, 2005).

5.4.3 Choice of Mixed Methods

Both a quantitative and qualitative approach using both questionnaire and interview formats allow focus on events that occurred and permits researchers to grasp the lived realities of the energy industry (Sunden & Wicander, 2006). Accordingly, in order to understand the research problem and lived realities in Ghana, this study adopted a mixed method approach. The use of both methods in research has been widely supported by many researchers (Borrego, Douglas, & Amelink, 2009) (see table 5.1). For the quantitative research portion, a questionnaire was employed whereas the qualitative research employed in-person interviews and informal semi-structured interviews. Qualitative and quantitative approaches are entirely opposite approaches in research, therefore, researchers are encouraged to use both approaches in understanding social phenomena (Borrego, Douglas, & Amelink, 2009).

Quantitative	Qualitative
Internal Validity	Credibility
External Validity	Transferability
Reliability	Dependability
Objectivity	Conformability

Table 5. 1 Comparison between qualitative and quantitative

Source: Babbie & Mouton, 2001

5.5 Sources of Data and Methods of Data Collection

Primary and secondary data collection was undertaken for this study. The primary data collection consisted of in-depth interviews with twenty one stakeholders in Telecom and Energy industry including representatives of mobile Telecom companies in Ghana. The interviews helped the researcher to obtain a better understanding of the energy challenges and other related issues in the Telecom industry.

5.5.1 Primary Data Source

The researcher used alternative methods including in person interviews, questionnaires surveys and field survey, unstructured interviews as a convenient method for gathering facts, opinions, behaviors and attitudes. In-depth interviews was conducted with experts in the Telecom and energy industry as well as representatives of mobile Telecom companies in Ghana. The collected interviews helped the researcher to obtain a better understanding of the energy challenges and other related issues in the Telecom industry. During the course of the survey, direct observations were used as a supportive technique in complementing the information from the interview. The photographs taken also provided a visual account which enhanced analysis (Patton, 1990). Table 5.3 gives an overview of the linkage between the research questions, research objectives and the methods used for data collection.

5.5.2 Secondary data

Secondary data collection was collected from existing sources within the Aalborg University Library in Copenhagen. Further literature searches concerning Ghana were carried out while conducting required fieldwork. Based on the research structure, information and documentary were collected from different stakeholders in Ghana (see Table 5.2).

Stakeholders	Documents Collected	Related Research Questions
Energy Commission of Ghana	PV development, utilization and acceptance in Ghana. Reports on solar and wind energy potentials. Reports on strategic National Energy Plan.	1 and 3
Ministry of Energy and Energy Commission of Ghana.	National Renewable Energy Technologies Policy and implementation document. Institutional Structure and Regulatory Frameworks on PV in Ghana. Rural Electrification Policy Document. Market Model on PV in Ghana. Report on Rural Electrification implementation Document	1, 3 and 4
Ministry of Energy	National Energy Plan Projects document. Energy sector development Program document. Report on Ghana 'energy consumption pattern.	3
National Communication Authority	Reports on performance of Mobile Telecommunication in Ghana.	1
Volta River Authority and University of Ghana library	Reports and academic lectures on socio-cultural activities in Ghana	2

Table 5. 2 Stakeholder Document and Research Question Relationship

Item	Research Questions	Research Objective	Methodology
1	How can renewable energy application enhance Telecom/ICT operation in Ghana?	To investigate the feasibility of renewable energy use in Telecom	Interview and Survey
2	What are the critical factors influencing sustainable development of Telecommunication and ICT use in Ghana?	Identify barriers and drivers of ICT	Interview and Literature review.
3	How does the unreliable supply of electricity affect the operations of the mobile Telecom operator?	To investigate the effects of unreliable power supply to the Telecom companies	Interview and Survey
4	How would a framework be modeled to incorporate the challenges hindering sustainable ICT application?	Identify and apply appropriate design theories and principles in respect to the development of SEAT framework.	Attempt to develop a model
5	Can renewable energy provide reliable electricity for the base transceiver stations in Ghana?	Examine the economic viability of renewable energy use by the Telecom operators	Simulations
6	**What will be the financial benefit/cost of renewable energy to the Telecom operator?**	**Examine the economic viability of renewable energy use by the telecom operators**	**HOMER software simulation**

Table 5. 3 Summary of the Linkage between the Research Questions, Research Objectives, and the Methodology Used in the Study

Raw qualitative data were gathered during the field work through informal interviews, diary keeping and direct personal observations. Since the interviews in this study were unstructured, recorded conversational data collection permitted maximum flexibility. This enabled most of the respondents to candidly express their views and perceptions, confirming Marshall and Rossman's (1995) argument regarding qualitative research. Marshall and Rossman assert that respondents' perspectives on a given phenomenon of interest should be exhibited by the participants and not through biased perception of the researcher. Therefore, in order to minimize observer-induced bias and to provide meaningful, data for comparison, substantially different sets of questions were formulated (see Appendix A-1) for the Telecom/ICT operators and the stakeholders in the electricity industry.

5.6 Research Target Group

To ensure sufficient data was collected to address the research questions of this study, the following organizations were approached and interviewed:

- The six Mobile Telecom Operators in Ghana (Vodafone - Ghana, Maritime Telecommunication Network i.e. MTN-Ghana, Tigo-Ghana, Airtel-Ghana, Expresso-Ghana, Globalcom-Ghana).

- Government agencies with responsibility for energy policy (Ministry of Energy and Energy Commission).

- Electricity Generation and Distribution Companies.

- Agencies with responsibility for telecommunication regulations (Ministry of Communication and National Communication Authority).

- Agencies responsible for environmental protection.

- Energy think-tanks and renewable energy experts.

- Opinion leaders in the selected case study areas.

5.6.1 Selection of Representatives of Respondents Telecom Operators, Energy and ICT Policies Stakeholders

Different stakeholders from various organizations participated in this study. These stakeholder bodies included private Telecom operators (i.e. Maritime Telecommunication Network, Vodafone, Tigo, Airtel, Expresso and Globacom), government agencies (i.e. National Communication Authority, Volta River

Authority, Ministry of Communication, Electricity Company of Ghana, Energy Commission of Ghana), private consultants (i.e. energy think-tanks, environmental organization), civic leaders (i.e. assembly men/women, opinion leaders) and the District Chief Executives of Ho, Kintampo and Ada districts.

Since the national economy of Ghana revolves around the business activity in the national capital, Accra, all the telecommunication service providers, software development service providers, the government agencies and other stakeholders are localized in the capital. In addition, energy and ICT infrastructure and their regulation are under the jurisdiction of the state and most policies and decisions are made in Accra. The government officials with the authority to formulate national energy and ICT policies are primarily located in the capital. Therefore, the interviewees selected from the Telecom operators, policy makers and private consultants were within Accra. The selected interviewees from these organizations and agencies are elite. This somehow made the interview process easy because they were familiar with the intricacies of their organizations and were able to report on the policies and future plans from an experienced perspective.

In order to understand the feeling and aspirations of the rural dwellers and have a uniform representation, three interviewees were selected from each of the three selected study sites.

They include the assembly men/women, opinion leaders and district chief executives. In addition, interviews were conducted with the local law enforcement agency (District commander of Police) of the selected areas within the context of service provision for law and order in relation to theft and destruction at the base stations. One person from each of the Telecom companies and other stakeholder organizations was considered sufficient to answer the interview questions for these organizations.

A non-governmental organization, Friends of the Earth was chosen because they are a known organization dealing in energy and environmental issues. Though, other environmental organizations exist, they were not selected because their activities did not include energy issues. The people interviewed from the energy think-tanks group include private solar PV companies, such as: solar light company, DENG Ltd., Solar Utilization Network (SUN) and energy consultants to articulate the views on energy issues.

A total of 21 interviews were conducted with different stakeholders (see Table 5.4). Each interview lasted for about 45 minutes so as to maintain cooperation and the accurate responses.

The fieldwork was conducted between August and December 2012 and it helped us in appreciating the challenges encountered by Telecom and ICT use in different parts of the country.

Type of Stakeholders	Stakeholder Bodies	Interview
Telecom Operators	Vodafone Ghana	2
	MTN Ghana	2
	TIGO	1
	Airtel Ghana	1
	Expresso	1
	Glo Ghana	1
Policy Makers (Telecom/Energy)	Ministry of Communication	1
	Ministry of Energy	1
	Ministry of Environment	1
	Energy Commission	1
	National Communication Authority	1
	Volta River Authority (VRA)	1
	Electricity Company of Ghana (ECG)	1
	District Chief Executives	3
Private Consultants	Energy Think- Tanks	2
	Solar Companies	2
	Friends of the Earth	1
Grass Root Participant	Civil Leaders (Assembly men/women and opinion leaders)	6
Law Enforcement Agency	DCOP	1
Total		**30**
Questionnaire	**Civil Society**	**60**

Table 5. 4 Details of Interviewed Organizations and Opinion Leaders

5.6.2 Selection of Study Sites

An important component of the research process was site selection. According to Berg (2004), an inappropriate site selection could weaken or ruin the final outcome of the studies. Therefore, studies should be conducted in locations that are appropriate to obtain the most relevant data for the study (Berg, 2004). Therefore, we considered two processes in site selection for our study. The first process which involved the selection of the capital, Ho, was based on the following reasons: (i) the weather condition is well known for several hours of uninterrupted sunshine, (ii) it is the political and administrative capital of the Volta region and (iii) it is also the commercial hub within convenient reach of the researcher and has an estimated population of 272,000 (Ghana Statistical Service, 2010) (Ghana Statistical Service, 2012)

The other selected areas were Ada-Foah and Jema and were based on a literature review and interview with an official from the Ministry of Energy and Energy Commission of Ghana. Required criteria for these chosen sites included strong wind speed and prolonged sunshine.

During the interview with representatives of Energy Commission of Ghana, Ada-Foah, Lolonya, Mankuadze, Aplaku and Petu (i.e. the coastal belt of Ghana) came up as areas with average wind speed in the range of 6 - 6.3m/s at a 50 metre - height corresponding to 185 - 210w/m^2 at 1.225kg/m^3 of air density. Jema which is district capital of South Kintampo in the Brong Ahafo region, Odonkorkrom within the Afram plains of the Kwahu South district in the Eastern region, and Yakese in the Enchi District of the Western region were also identified as areas where some solar PV systems are being used. It became prudent to select most convenient site for wind and solar sites for the case study. The specific field sites that were chosen were Kabakaba Hill in Ho Municipal, Ada - Foah in the Dangbe East District and Jema in the Kintampo South District assemblies (Figure 5.4).

Figure 5. 4 Map of Ghana showing the study areas.

5.6.3 Description of the Study Area

Field studies were conducted in three different locations within Ghana: Ho, Ada-Foah and Jema.

5.6.3.1 HO

This segment of the study starts with Ho which is located at about 165km from the capital city of Accra, Ghana. It is the capital town of the Volta region of Ghana. Ho municipal assembly shares boundaries to the South with the Adaklu-Anyigbe district assembly. It is engulfed on the West by South Dayi district assembly, to the North by the Hohoe district assembly and to the East by the neighboring country, Togo. Ho lies between latitude 6°207´N and 6°55´N and longitude 0°127´E and 0°53´E. It has an average sunshine duration of 6.2 per day.

5.6.3.2 Ada-Foah

The study also focused on an analysis based on Ada-Foah, which is the district capital of Dangbe East district in the Greater Accra region. It is within the latitude of 5°45´South and 6° north and between longitudes 0°20´W to 0°35´East. Dangbe East district shares borders with North Tongu District at the north, Dangbe West District to the west and South Tongu District to the east. At the south is the Gulf of Guinea, which stretches over 45 km. Ada-Foah has a consistent wind speed of 6.4m/s with substantial sunshine of 6.2 hours daily.

5.6.3.3 Jema

Jema, our third study site, is in the Kintampo South District of the Brong Ahafo region. Kintampo South lies between latitude 8°15´N and 7°45´S and between longitude 1°21´W and 2°10´E. Kintampo South district is bordered to Kintampo North, Nkoranza and Techniman, Atebubu and Pru districts in the North, South and East, respectively and to the west of the Wenchi Municipal assembly. It was chosen in order to broaden the scope on the discussion of solar PV project implementation and sustainability in rural parts of Ghana. In addition, Jema is the district administrative capital with abundant virgin land which is suitable for growing cash crops. The nature of the soil on the land has attracted many migrants from different parts of the country who are currently engaged in commercial crop production. This site therefore offered the opportunity for Telecom and ICT deployment.

5.7 Questionnaire

The content and design of the questionnaire and interview questions were guided by the research aims of this study. The initial preparation of the questionnaire and interview questions used in the field started at CMI-Denmark (Aalborg University, Copenhagen) and was finalized in Ghana. The questionnaire contained both facts and opinion questions while the interview questions were entirely dependent on opinions. Some of the factual questions were straight forward questions. Other questions were open-ended to allow the respondents to have the freedom to provide their own responses. The questionnaires were directed at the representatives of the Telecom operators, the Telecom stakeholders, electricity providers and electricity stakeholders. (See Appendix B1-B3).

The questionnaire focused on issues relating to energy sources for the base stations, reliability of power supplied, the type of mobile phone network equipment being used, power consumption of the network and other challenges at the base stations. Informal interview questions, however, did not have a specific structure, because an answer to a question could trigger comments and queries on a different issue. We used a 5-point Likert scale which ranged from strong agreement to strong disagreement. The respondents were reluctant to disclose the amount of money spent monthly on fuel and maintenance of the diesel engine generators (DEG) on each base station, because they felt the questions were too direct and specific and could reveal information to their competitors to know details of their maintenance expenditure. Consequently, we changed the structure of questions relating to cost of maintenance and expenditure incurred at the base stations to indirect forms of determining cost (e.g. fuel cost, transportation costs, replacement parts cost, and spare parts cost) were built into the questioning (see Appendix B1).

5.8 Gaining Access to the Field Sites

The stages in achieving physical access and social access to the selected sites during the field surveys to collect data is essential (Feldman, Bell, & Berger, 2003). Therefore, this study considered a number of factors in planning access to the selected sites.

First and foremost, access to a group of research subjects may require extensive consultation and permission of authorities. Secondly, cooperation from individual members of respondents is required in order to maximize response while ensuring information consent (Frohlich, 2002). In this study, field site access exhibited few hindrances thus making cooperation feasible. Few hindrances were encountered because the Telecom operators have their head offices in Accra and once permission was obtained the necessary support (e.g. survey participation) by their staff in the selected sites was granted. Fortunately, the researchers spoke fluent Ewe and Dangbe languages, which are the local languages spoken in Ho and Ada-Foah, respectively, thus minimizing potential communication issues. However, in Kintampo South, some local people at the case study site were asked to assist because the researchers could not speak the local dialect, Twi. Aside from the permission from the Telecom operators, access to field sites in Ho, Dangbe East and Kintampo South districts were first sought from the district coordinating directors. After receiving access, permission was also sought from the traditional rulers and their elders in the selected sites. Assembly members were also informed, because they are the civic leaders of the villages and can therefore assist visitors in different ways. In all, in the process of negotiating access to the study sites, the respondents of the chosen field sites were assured of confidentiality.

5.9 Research Diaries

Diary keeping was another methodological approach helpful in collating data in the field. The purpose of field diary recording was to keep track of events that took place in the field as the study progressed over time. In this research, the diary helped to document details on how field site access was obtained. Also, through the use of a field diary, dates of interviews, the people interviewed, daily schedules and all challenges that were encountered were noted.

5.10 Sampling Techniques

Based on the nature of our research problem and the need for representative samples, simple random and purposive sampling were the techniques utilized in selecting the sampling units.

Simple random sampling was used in selecting wind speed site in Ada –Foah because, all the coastal towns along the gulf of Guinea in Ghana thus stretching to the Ghana/Togo border has high wind speed and were given an equal chance of being selected.

Purposive sampling was used to select the informants from the Energy Commission, the Ministry of Energy, the Ministry of Environment, the National Communication Authority, ECG, VRA and the Energy Think-Tanks. Within these organizations, high profile employees were selected for an interview, because of their involvement in the energy policy issues. The selected interviewees from the Telecom operators were chosen due to their responsibilities which included the decision on the energy use within their respective companies. Thus, they are deemed an appropriate repository of knowledge on the energy issue. Purposive sampling was also used to select the assembly men/women, District Chief Executives and District Commanders of Police in all three districts. Purposive sampling was done deliberately because, the officers were selected according to our own knowledge and opinion about which one is deemed appropriate to the topic area (Barbour, 2001).

5.11 Data Analysis

After the interview and questioning, the researcher's notes were carefully examined for clarity. Collected data were grouped for the purpose of easy analysis. For example, the questions associated with the distributed questionnaire for the mobile Telecom operator were grouped into the following categories:

- Authority of respondents: Question 1. The aim here is to appreciate the authority level and influence of respondent in decision-making in the organization.
- Mobile coverage: Question 2 and 3 aim to understand the operational areas of the company and verifying their coverage areas in the mist of the numerous challenges.
- Electricity supply challenges: Question 4-11 aim to establish the veracity or invalidity about the frequent power outages and how these outages affect the smooth operation of business.
- Environmental awareness and concern: Question 15-17 aim to establish the level of environmental awareness pertaining to the negative effects of Telecom operations, especially the burning of diesel fuel for electricity production.
- Alternative power supply suggestions: Question 12 and 13 aim to find the preferred alternative power source for uninterrupted operation of the Telecom businesses and the kind of incentive and privileges Telecom operators stand to derive from regulators and stakeholders.

The questions for the ministries, energy stakeholders and regulatory authorities were also grouped as:

- Authority of respondents: Question 1. The aim was to appreciate the authority level and influence of respondents in decision-making in the organization.
- Functions of organizations: Question 2-5 aim to gain an understanding of the roles being played by all stakeholders in electricity production and improvement in Telecom service delivery in Ghana.
- Perception of renewable energy use: Questions 6-9 aim to establish the barriers that prevent the fast development and adoption of renewable energy as an alternative source of electricity supply.
- Framework to mitigate energy crises: Questions 10-13 aim to understand if there are programs and facilities in place to mitigate the energy crises of the country as well as promote the development of ICT.

The collected data was analyzed and interpreted through qualitative and quantitative forms of analysis. Qualitative means of analysis that were employed, included the transcription of audio recorded interviews, content analysis of secondary data and transcripts of interviews, institutional analysis and conversation analysis to reveal key themes and issues. Olympus digital speech standard (DSS) pro-5000 computer transcription software was used to transcribe the audio recording. After transcription, content analysis was used to manually tease out themes and develop a model from the data. This was done by arranging the transcripts and texts from the secondary data into various categories and levels. These categories were examined using content analysis to determine relationships amongst the categories. These relationships then became the theme to be used in the analysis. The validity of conversational data was analyzed using conversation analysis. In order to maintain high levels of confidentiality of informants and interviewees, their names were replaced with identifiable codes, or in the present case, letters of the alphabet (e.g. A, B, C).

NVivo software (version 10) was used to analyze both qualitative and quantitative questionnaires. Also data were manually rearranged and further analyzed using HOMER energy modeling software. The HOMER energy modeling software is a computer modeling program that provides the detailed rigor of sequential simulation and optimization in a model. It is capable of modeling both technical and economic factors involved in a project. HOMER provides comparative cost and feasibility analyses pertaining to the various energy configurations.

5.12 Constraints of field work

There were few practical issues that affected the field work activities. Some of the encountered challenges during study implementation were lack of cooperation from the interviewees of the Telecom companies who were uncomfortable sharing details related to expenditure for fear of financially exposing their organizations. It was also difficult to obtain answers to questions about the total energy consumption at co-located sites where two operators depend on common power distribution. One of the operators did not have a substantive maintenance head and so could not respond to the interview questions.

With regards to stakeholders, it was difficult to interview officers from the public ministries, and from one private company, because of general and mutual mistrust. These stakeholders were extremely skeptical about confidentiality. Some just did not seem to have any concern about the effect of the power generation. Some interviewees were reluctant to discuss issues concerning the amount of money spent on energy utilization in order not to be victimized by their employers and some of the prospective interviewee and respondents were not available. As shown in Table 5.4, not all sampling units were covered in the field work.

In all, six potential respondents could not be interviewed either due to non-availability or abrupt rejection. In the Ministry of Energy and VRA – GRIDCo, it was not possible to interview their staff because we were abruptly thrown out. Although we went to the offices of these organizations, the receptionists demanded that we specify the names of the officers or else we would not be granted permission. These types of challenges are common and it is cautioned that, when conducting interviews in different cultural contexts, especially in developing countries, care and sensitivity must be considered (Bull, Valentine, & Williamson, 2009; Heary & Hennessy, 2002).

Another field limitation was the absence of a proportional representation from women in the survey, resulting in a clear gender bias among the interviewees. This skew is normal in Africa, as women are rarely found in leadership positions. Women in Ghana hardly take up certain types of professions which are seen as masculine in nature. This pattern of gender representation and behavior in data collection in developing countries was well articulated by many researchers (Howard, 1997).

Another interesting challenge was that some of the interviewees disliked the use of a tape recorder, although the importance of taping and our position as students was explained to them. In particular, some of the interviewees only agreed to be interviewed provided their voices were not recorded. This type of behavior (e.g. rejection of voice taping) in developing countries is also well known (Bull, Valentine, & Williamson, 2009). Few institutions were also reluctant to release secondary information at the first visit because they wanted to verify the proof of our identity. We were, however, able to convince them by assuring them of our status as students by showing our student ID and complimentary cards.

5.13 Authority of Respondents

The responses were based on the experience of key maintenance and planning officers who were nominated by the mobile Telecom companies and responsible employees within the middle and top management positions of the other stakeholders. Two of the six companies would not grant interviews. The remaining respondents who participated consisted of key personnel within the power and planning departments of the mobile Telecom companies. These selected personnel are responsible for the power system planning and their proposals and decisions form part of their corporate businesses.

5.14 Triangulation

In research, validation of approach is required in order to ascertain that the findings of the research are accurate and empirically trustworthy (Denzin, 2009). It have been accepted that, validation of research should have more than one method to improve the impression that the results are valid. This study integrated qualitative and quantitative approaches which were labeled as ‘between (or cross) method’ triangulation (Denzin, 2009).

5.15 Reliability and Validation of the study

A qualitative research method often depends on a single case, whereas quantitative research methodologies use multiple samples. In using a qualitative research method, the generalization of an outcome becomes quite difficult because of the small sample size. The challenge associated with quantitative research methodologies has been the common survey mistakes (Denzin, 2009). For example, a respondent may have a different answer to a question posed in a questionnaire, yet he or she only has to deal with the answers provided by the researcher. Also, there could be mistake(s) during the time of entering the information into the computer. To avoid this, qualitative research questions should not be ambiguous, rather they should follow logic to enable the respondents to understand (Baqir, 2009) (Berg, 2004). The researcher used careful planning and implementation of questions to avoid some of these common mistakes.

5.15.1 Reliability

Reliability is mainly used in testing or evaluating quantitative research (Berg, 2004). However, it can also be used for evaluating both qualitative and quantitative research (Borrego, Douglas, & Amelink, 2009). When reliability is the concept of a research, the results are determined by the quality of the quantitative study (Borrego, Douglas, & Amelink, 2009). Unlike quantitative research, the quality concept of qualitative research aims to create an understanding of relevant challenges (Golafshani, Understanding Reliability and Validity in Qualitative Research, 2003). Thus, qualitative research helps to improve the quality of results which is a valuable test of the study. The difference in qualitative and quantitative evaluation turn to negate qualitative research. Therefore, the concept of reliability is said to be confusing and has some consequences if it is used as a benchmark for evaluating the reliability of a qualitative research study (Stenbacka, 2001).

5.15.2 Validity

Validity in a study determines whether or not the objectives of a study have been achieved. Objectives are considered attained if the research questions and target audiences are appropriately chosen to represent the population. If we consider a quantitative research method, the audiences are chosen at random. But for qualitative research, the audiences are carefully selected (Golafshani, 2003). During qualitative research studies, the measurement methods of dependability, credibility and transferability are consistent (Golafshani, 2003). The use of dependability means that the results can be compared with any prior studies of the same phenomena. The credibility implies that the research is sufficiently robust to portray the image of the phenomenon and transferability describes the ability of the result being use or replicated in other studies or subjected to further research (Shenton, 2004). The reliability and validity of this research was supported by the fact that all the sources used in this study were reliable and relevant to the topic. The reliability of the study was acceptable because the target group for the study represents the population. Also, the survey and interview questions were acceptable and correlated to the aims of the study. The questionnaires and the interview questions were truly fair and clearly written. Lastly, the triangulation approach in the study was considered reliable and objective.

5.16 Summary

This chapter has presented detailed accounts of the research philosophy, strategy and methodology that were adopted for this study. The study was placed in a pragmatist paradigm, using both positivist and interpretivist ideology to successfully use approaches in data collection and analysis based on: surveys, interviews, and case studies. The use of qualitative and quantitative approaches required interviewing of mobile Telecom operators, Telecom stakeholders, assembly men and assembly women. Semi-structured and open-ended questions were developed and utilized. The semi-structured questionnaires were used to facilitate smooth interviews with the purpose of gathering information on energy use at the base transceiver stations (BTS) and the impact of unreliable electricity supply. In addition, the interview with the regulatory authorities was aimed at finding an alternative source of power generation for the BTS.

The open-ended questions were used to collect information from the interview with representatives from the mobile Telecom operators and other stakeholders responsible for both telecommunication and power generation. The one-on-one interviews conducted by the researcher to gather data from the participants represented a kind of primary method of data collection. The use of quantitative and qualitative approaches complemented each other in answering the research questions. These are the components of triangulation.

In addition, this chapter emphasized challenges that were encountered during the interviews. Most of the constraints encountered in the field were anticipated and they were not peculiar only to this study alone. Finally, culturally appropriate fieldwork methods were deployed to overcome some of these challenges.

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Chapter 6: Discussion of Electricity and ICT Challenges in Ghana

6.1 Introduction

The previous chapter dwelled on the approach adopted for this study by explaining the methodology. Quantitative and qualitative research method approach was the focus. The present chapter discusses the findings on the challenges in ICT and electricity as well as discusses other dimensions of these main findings. The findings revealed the current electric power situation and the present use of ICT facilities in Ghana. The sources of electric power generation, electricity demand and supply in both urban and rural areas has been examined. The study found unstable power supplies and poor telecommunication networks to be one of the challenges facing Ghana's ICT development. Electricity supply was identified as an important factor from our data sources and it is obvious that the availability and quality of the supply is paramount (Caspary & O'Connor, 2003). Researchers have determined electricity to be an essential component of infrastructure that makes access to ICT beneficial (Batchelor & Norrish, 2003). They also took note of the relevance of electricity in their studies. Batchelor & Norrish (2003) pointed out that any infrastructure that will promote technological advancement is a key infrastructure, and here in our case it refers to a reliable electric power supply.

As discussed in earlier chapters, by virtue of Ghana's geographical location it has abundant renewable energy resources. The country has abundant solar energy with a daily solar irradiation ranging from 4 kWh/m^2 to 6 kWh/m^2 and corresponding annual sunshine duration between 1800 hours and 3000 hours. But there are geographic variation in both direct and diffuse radiation levels. There is low diffuse radiation in the northern sector, the coastal belt along greater Accra and Central regions of the country. But most part of the southern part of the country have high radiation diffusion rate. Ghana also has more than 2000MW wind energy potential (Hamlin and Ofori Nyarko, 2005). There is also high wind regime along the coastal belt and some isolated areas in the Upper region of the country. The boundary between Ghana and Togo has the strongest wind power resource with an annual mean greater than 9 m/s.

6.2 Electric Power Situation in Ghana

Currently, Ghana has an installed capacity of 1180MW of hydropower electricity from Akosombo and Kpong. Thermal energy from Takoradi Thermal plants amount to 922MW while the independent power producers have 326MW. There is also 30MW diesel power generating plant in Tema. Though findings reveals the abundance of energy resource potential, they are not real viabilities. An example is, out of the 2420MW hydroelectricity generating potential, only 1180MW was installed until independent power producer commenced construction of 400MW in Bui.

As indicated in figure 6.1, the red line indicates electricity distribution in the country. At present, about 72% of the population have access to electricity.

Due to population growth, urbanization and economic expansion, the demand for the country electricity is increasing steadily. But the low generating capacity of the power plants coupled with outmoded distribution network highlight the energy security of Ghana and its adverse effects on sustainable Telecom development and other economic and social development. This supports (IMANI Center for Policy & Education, 2014) argument that "Ghana is…..far from attaining a state of energy security''

6.3 Technical Challenges with Electricity Supply in Ghana

By triangulating the findings through different types of analyses, we were able to identify Technical challenges associated with electricity supply as some of the findings in this study.

The first technical challenge is the low power generating capacity and poor electricity distribution network. The second constraint is the inability of local solar companies to connect to the national grid. Throughout the interviews these two constraints were mentioned more than ten times by eight of the interviewees.

6.3.1 Low Generating Capacity and Poor Distribution System

The poor quality of electricity supply in Ghana is due to the low generating capacity, poor distribution networks, and the improper maintenance and management culture. Interviewees from all the stakeholders repeatedly discussed the low power generation. The entire country of Ghana is saddled with a power supply crises and both Telecom and ICT activities are equally affected. The responses show that grid electricity supplies are connected to the Telecom BTSs within the capital city, the regional capitals and all urban centers. But the primary complaint was about the intermittent power outages that are rendering the use of ICT ineffective for nearly three to four hours per day.

Vodafone - Ghana and MTN are the only two telecom operators that have extended their network to the rural areas where there is no grid supply and therefore depends on their own expensive DEGs for electricity. This is due to the fact that the operators want to avoid disruptions in communication. DEGs continue to operate most of the time in both cities and urban areas.

According to the respondents, they have not enjoyed a continuous electricity supply for a week. This excludes the intermittent power fluctuations and surges. Again, because monitoring of the BTSs is done through physical visits to the sites, the power maintenance team has to visit each BTS at least twice per week to either check on fuel supplies or perform routine maintenance in order to maintain excellent communication links.

6.3.2 Grid Connectivity

During the interview, the local solar companies, Energy Think Tanks and other stakeholders are of the view that issues surrounding grid connectivity in Ghana is dicey. By the later stages of the interviews, stakeholders were quick to express their frustrations. A number of the stakeholders we interviewed stated that the centralized power generation and distribution system currently being used in Ghana creates barriers for the introduction of renewable energy, especially concerning access to the national grid.

The current situation in Ghana is that taxes are only reduced for solar panels and not the other components like inverters and batteries. An energy bill has been presented at parliament to give renewable energy the impetus to develop. The bill permits renewable energy suppliers to generate power using their various sources and to feed the national grid with the surplus. Under this arrangement, every individual with a solar source will become an energy provider. This will enable a transition from a centralized grid with a single energy provider to one with many providers. It is not surprising that the power generation and distribution companies (i.e. VRA and ECG) are reluctant to permit diversity in the sector. Through explanations from an interviewee, it was clear that monopoly holders enjoy being comfortable because they have absolute control under the centralized system.

All the respondents from the telecom operators have a common view that the power crises in the country are affecting their operations and performance. This is because the officers always move to all base stations regularly to ensure effective functioning of the generators. According to them, because of power fluctuations, they have altered the settings on the control systems in order to prevent damage to their equipment. They do this by making sure the DEGs do not immediately respond to the availability of electricity and rather initiate after monitoring the supply for up to 30-45 minutes.

The issue of power interruption has been a challenge to all of the respondents, and therefore is of great importance to their companies. The red lines on the map of Ghana in Figure 6.1 shows areas in the country where grid electricity supply is available.

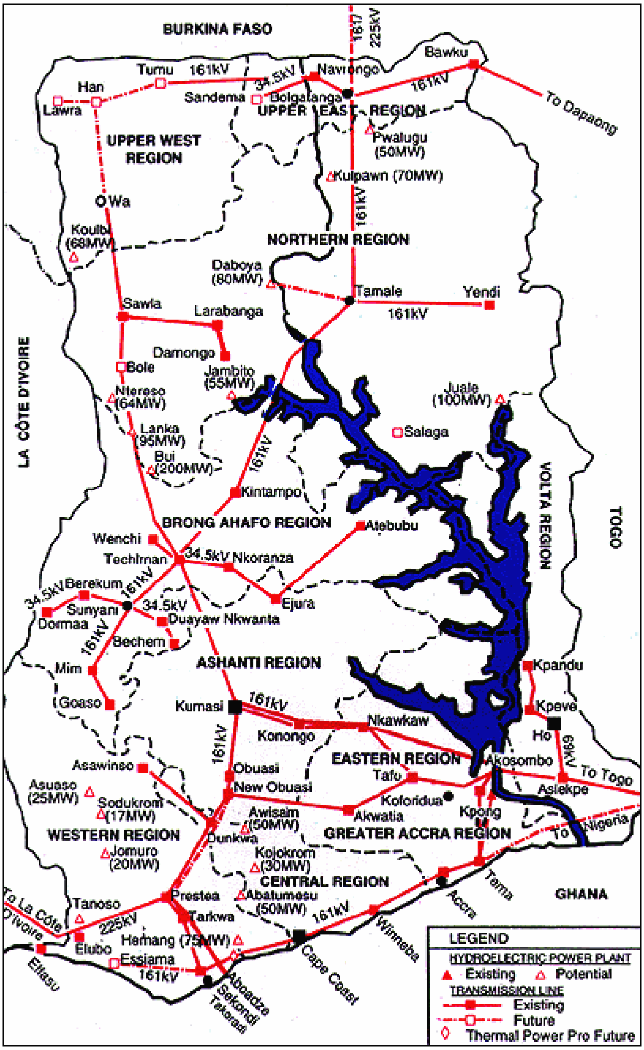

Figure 6. 1 Grid electricity distributions in Ghana (Source: GRIDCo, 2010).

An interviewee discussed how grid connection will be related to resource constraint. He explained that the core business of the Telecom operator is not about electricity and therefore will have technical, human and informational challenges. Even though these constraints are genuine and confirmed by other interviewees, we were astonished at the divergent views expressed by other sets of respondents. For example, some emphasized technical constraints while others dismissed them and instead blame it on politics.

6.3.3 Difficulties of Introducing Renewable Energy

Analysis of the field survey also raised technical issues surrounding the introduction and acceptance of other forms of electricity supply which is not from the national grid. Technical efficiency of solar PV and qualified installation and maintenance technicians were the important issues. This support the views of others (e.g. Roger, 1995) that the perceived difficulty of learning to use and understand a particular technology can affect the acceptance of that technology. This study revealed that the Telecom companies attributed their non-use of solar PV and Wind energy to the lack of technical know-how and perceived complexity of these technologies. Some of the representatives of Telecom companies and officials from the ministries collaborated each other's story that the lack of technical know-how of Solar PV and Wind energy technologies is a challenge and assume it will be complex since the technology in still new. A senior civil servant from the ministries indicated that "There is a lack of technical capacity that can expose the capacity and benefits of solar PV in Ghana''. An expert from the energy think-tanks also stated that "some people in Ghana do not understand how solar PV works and are therefore not willing to use it''.

Another issue raised is the low efficiency of the solar PV output. They expect a very long lifespan of the solar PV components (if not everlasting), the cost to be very cheap and also they are expecting the solar PV to power every device including air conditioning units and refrigerators. This creates lack of confidence and uncertainty about the efficiency among the Telecom companies. The lack of consensus among the stakeholders regarding the primary constraint created a lot of uncertainty about the easy acceptance of renewable energy technology as an alternative to the existing system. The stakeholders never had a collective agreement on the percentage of renewable energy that should be connected to the national grid. The most common word used related to constraints in the solar industry was 'government' and the most common phrase used was "we are tired with the power outage''.

6.3.4 Qualified Technicians

Another aspect of technical challenge is the absence of qualified installation and maintenance technician(s). The respondents mentioned the lack of qualified technicians that will competently maintain the solar PV and Wind turbines as a challenge. These complains has great influence on the decision makers in accepting these technologies.

6.4 Political Uncertainty

Political uncertainty is an aspect of challenges which is vital in the introduction, acceptance and use of renewable energy. Ten interviewees discussed political influence as a constraint during the interviews. One of the interviewee explained how politicians try to claim the glory for the current energy bill to promote their political party's agenda and by blaming the previous administration for not making grid connectivity accessible. The interviewees expressed frustration over decisions that they believe were made based on political expediency and possible individualistic gains. They were consistent in their beliefs that decisions were made based on short-term political maneuvering and not in the best interest of business or the long-term interest of the country.

Politicization of renewable energy especially solar PV and Wind energy by some individuals in authority or those with political ambition heighten the uncertainty about the feasibility of the technology; even senior management personnel stakeholders in the industry hold varying views and opinions on some of the issues.

Political comments against solar as being inferior form electricity generation and making promises of extending the national grid to every part of the country have negatively influence its acceptance. During the interview with the representative from the Energy Commission of Ghana, indicated that the use of "comparison of solar PV and national grid by politicians during electoral campaign has discouraged many individuals and companies from accepting solar PV'' (Representative of EC-GH). He said "our politicians have made solar PV look inferior to the national grid because aspiring members of parliament and presidential candidates promised the electorates that if they voted for them, they will ensure the national grid is extended to every part of the country'' (Representative of EC-GH).

This comments creates doubt and serious implementation constraint. For example, investors are becoming reluctant to invest in the solar energy industry. They are becoming discouraged and are unwilling to purchase and install solar panels. These constraints are preventing the energy industry from growing. This has affected other sectors that could have benefited from the utilization of renewable energy. An example regarding access to the grid is that solar companies could have been feeding the grid to reduce the level of unreliable services emitted to customers.

6.5 Institutional Factors

The study revealed that existing states policies and institutional measures that support solar PV and wind energy also contribute to the lack of acceptance of the technology.

Policy and institutional measures of renewable energy in Ghana which dates back to 1983 should have boost the acceptance of all renewable energy application, but due to ineffectiveness of institutional arrangements, solar PV and wind energy are looked down upon. This study view the institutional structures for renewable energy as a hindrance to solar PV and wind energy technology development. Because the structures have not promoted an even playing field that will enable solar PV and wind energy to compete with the national grid. The study also identified that, there are no clear distinction of functions between the activities of the Energy Commission and the Ministry of Energy. There is also poor co-ordination between solar PV companies and the Ministry of Energy.

6.5.1 Public Policy Supporting Electric Power Generation in Ghana

The earlier sections revealed electricity generation technologies in Ghana. The analysis shows that, though there is significant potential for solar power and wind energy across Ghana, their present share in the country´s energy mix is negligible. This is partially due to historical development of the energy sector in country. The electric energy sector in Ghana was inherited from the country’s colonial masters (British) which was planned and developed in a centralized and subsided way with preference for diesel power plants and large hydropower dam. Another reason is that solar power and wind energy technologies were not well-known and are considered expensive means of electric power generation. In order to conform to international fuel mix requirements and decrease the impact of energy sector on the environment, Ghana government started to introduce policy and measures for the promotion of renewable energy in the 1990s. This section presents an analysis of public policy related to Renewable energy in Ghana that was adapted.

6.5.2 Energy Strategy of 2008

The fundamentals of the energy policy in Ghana in the recent years are set to guide the transition of Ghana’s energy sector to a free market based type in accordance with World Bank requirements. In the strategy, the introduction of free energy market and competition are seen as the solution for energy crisis in the country since electricity generated for the country is inadequate for the population.

The main principles followed by the Ghana government are (i) Creation of legal, regulatory and market environment prior to the implementation of new large-scale investment and privatization projects (ii) proactive energy efficiency policy for the country (iii) positioning Ghana as a reliable country of the future and market center for providing electric power in the sub - region of West Africa.

At the time of preparing this report, a new energy strategy for Ghana is under preparation. This new strategy is supported by the World Bank and is been prepared by a team led by the Energy Commission of Ghana. According to well informed expert representatives of the Ministry of Energy, the new strategy provides a preferential tariff to support renewable energy in general but with a particular preference for solar photovoltaic and wind power.

Although promotion of Renewable energy Technologies were mentioned in various contexts in existing energy policy documents, (National plan for economic development; 2000-2010 and National strategy for environmental protection; 2000-2015) the policies do not seem to be well coordinated.

For example, there was no mention of electricity generation from renewable energy resources in the National plan for economic developments (2000-2010). However, promotion of natural gas was included.

6.5.3 Programmes and Action Plans for Energy Efficiency and Renewable Energy.

There are no programs or action plans targeted directly at the promotion of renewable energy particularly solar power and wind energy, but renewable energy technologies are included in the various programs on energy efficiency. Several programs on energy efficiency were prepared in the last decade, but only a few of them were adopted and even those adopted were abandoned due to lack of funds. There are no target or any definite mechanism that will lead to the promotion of solar and wind in the various energy efficiency programmes, rather just a general suggestions and suggestions on how energy resources can be harnessed.

6.5.4 Environmental Impact Assessment

According to the existing environmental protection law of Ghana, the need for environmental impact assessment shall be considered for the construction of hydropower plants and thermal power installations (gas plants and crude oil plants) of 10MW and above. Most of the conditions of assessment are related to the areas where the power plant is to be constructed, the potential impacts on the ecosystem and the public interest in the project. Unfortunately, there are no forms of evaluating the environmental impact assessment and this is a big setback. At present, there is a growing concern among the Ghanaian population about the rapid increase in the use of diesel engine generator by many individuals because of the noise and carbon dioxide pollutions during blackouts.

6.5.5 Research and Development (R & D) Support for Renewable Energy

At the moment, there is very limited R&D support for renewable energy in Ghana and this limits the opportunities for creating cheap renewable energy technologies in Ghana. The Ghana Educational Trust Fund (GETFund) and Council for Scientific and Industrial Research (CSIR) are the possible sources of funding. GETFund provides general educational and academic assistance while CSIR supports scientific researches. Unfortunately, they both have different priorities which are far from renewable energy and they may not provide any assistance for research and development of solar photovoltaic or wind power.

6.6 Telecom Infrastructure

According to the responses, a substantial part of Ghana lacked basic Telecom infrastructure. The responses from the participants suggest that all the mobile Telecom operators in Ghana are using 2G and 3G technology and the operations do not cover the entire country. The coverage areas for two companies are quite extensive, while the remaining four are more concentrated within the cities and urban centers (Figure 6.2). Four interviewees indicated that Vodafone's coverage area is wider because they inherited the national network from the Ghana Telecom Company. Even though the radio links are good, the existing intra-city fixed lines were few, old and of poor quality. They attribute these repeated interruptions as the primary cause of trouble accessing the Internet. It is evident from the study that the lack of access to Telecom facilities in various parts of the country is the cause of poor ICT usage. Caspary and O'Connor (2003) similarly identified the lack of Telecom infrastructure as critical in the course of extending access to ICT throughout many developing countries, particularly in the rural areas. According to the data gathered from National Communication Authority, as in table 6.1, there are about 23,370,000 mobile customers with MTN having 46%, Vodafone 21%, Millicom 15%, Airtel-Ghana 13%, Glo 4% and Expresso 1% (National Communication Authority, Ghana, 2009) (Ghana Statistical Service, 2010). Data from Ghana Statistical Service (2010), also shows that only 47.7% of the population have mobile phone service with only 7.8% having access to the Internet services. We observed that due to poor access, individuals have several subscriber identification modules (SIM) cards and phones in order to have network access wherever they go. A number of the interviewees repeatedly said that greater measures for improvement in infrastructural development as well as establishing a responsible and responsive regulatory environment are the responsibilities of the government.

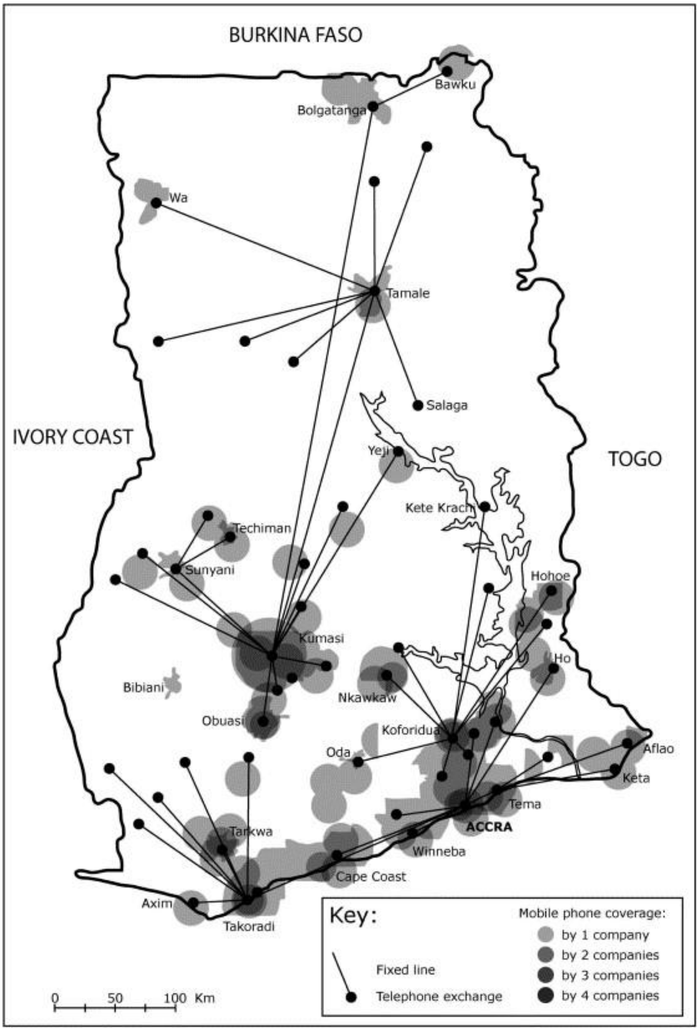

Figure 6. 2 Telecom network in Ghana (Source: NCA, Ghana 2010).

Company	Percentage of Market	Number of Customers
MTN	46	10.76 Million
Vodafone-Ghana	21	4.82 Million
Millicom	15	3.55 Million
Airtel	13	3.02 Million
Glo-Ghana	4	0.99 Million
Expresso	1	0.23 Million

Table 6. 1 The Share of the Companies in the Mobile Market

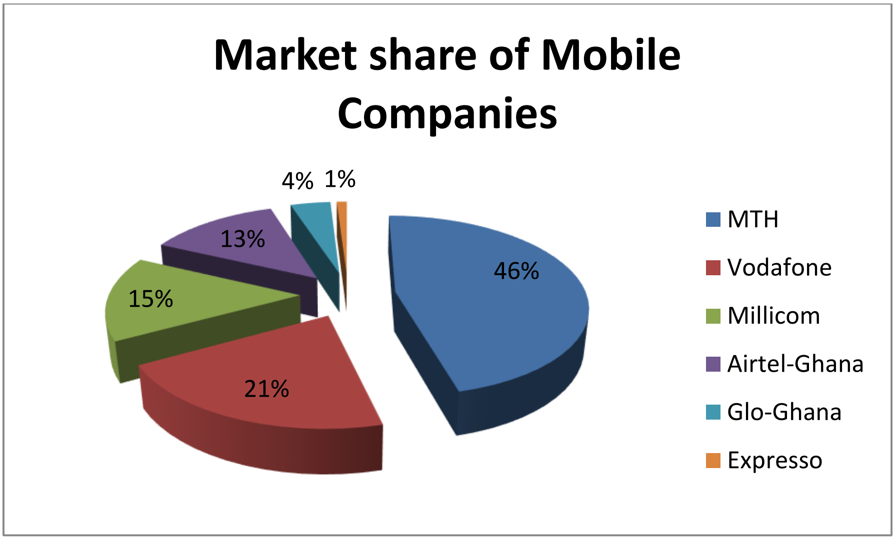

Figure 6. 3 Market shares of mobile companies in Ghana (Source: NCA, Ghana).

6.7 Challenges with ICT Development

The study also identified lack of basic education, poor knowledge on the environmental effect of ICT and ineffective Telecom market regulation as some immediate challenges to Telecom/ICT development.

6.7.1 Education

Basic education and education in ICT were identified by the interviews as minor constraints. The supervisory authorities of the Telecom industry were concerned about the slow pace at which ICT applications are adopted, especially by the elderly. They attribute this poor and sluggish adoption of ICT innovations to lack of ICT education. We can also trace this further where the majority of the elderly population, especially those residing in the countryside, never had access to any formal education and therefore cannot read or write. Unfortunately, ICT devices are coded in the English language, which is a foreign language in Ghana although it is the official language of the country.

The stakeholders emphatically mentioned that education enhances easy and fast adoption rates of an innovation. From the responses to the questionnaires issued, we gathered that many people were supportive of mobile phones because it enabled them to use local dialects to express themselves. However, sending and reading text messages is typically found among the educated youth, which we found were not the best for ICT promotion because the group of people who have the ability to implement change are in the minority.

With regard to personal computer and Internet usage, the Telecom operators noted that ICT and computer literacy are a constraint. From the responses, we identified that people with knowledge in personal computers have the upper hand in using ICT facilities than those without knowledge. Batchelor S., Norrish, Scott and Webb (2003) also notes that illiteracy is one of the major hindrances to socio-economic development. According to Rogers' theory of diffusion of innovation, knowledge of an innovation plays an important role and since the users of ICT can re-adapt the technology to suit their needs, education becomes even more important (Batchelor & Norrish, 2003). A typical example is the transfer of units, thus, instead of sending actual money for people to buy credit for their mobile phones, the credit is transferred directly to them.

6.7.2 Environmental Effects of ICT

The respondents have a fair idea about the environmental impacts of the Telecom and ICT industries, in general. One participant from a regulatory industry was very much concerned about the environmental impact of technological development. With the exception of three interviewees, all others said that there were no specific officers in their organization responsible for any activity related to environmental issues. According to the respondents, checks on carbon emissions and footprints are issues that organizations do not focus on.

6.7.3 Policy and Regulatory Challenges of the Telecom Market

Policy and regulatory framework for Telecom and renewable energy activities in Ghana were some of the issues commented on by the interviewee. Though, our focus was not very much towards regulatory markets. However, it is worth commenting on the awareness of government interventions and programs designed to make the regulatory environment more conducive. Analysis of the documents and interviews revealed that the current structure lacks innovative measures that will promote the introduction of renewable energy. The Telecom market have some challenges especially when the state was maintaining a monopoly on the industry. Under that circumstance, the government was the sole provider of services. The Telecom sector reform program helped in increasing access to telephone and Internet services.

6.8 Overcoming constraints

Overcoming the identified constraints will require a genuine effort of collaboration among the stakeholders in the Telecom and energy sectors. The Telecom operators are concerned about reliable power supply for their operation. However, they are not too sure of the alternative. We see collaboration as a creative approach and when combined with other resources, would enable the operators to better deal with the constraints. For example, they could join to protest the unreliable power supply to the BTS, and in doing so, could come out with a unified voice that represents all the operators as well as the renewable energy companies. Such collaborations can however, only result in a partial solution to the constraints. A creative example is the collaboration of stakeholders that was discussed by two of the interviewees. They stated that the mobile operators can collaborate and introduce renewable energy (e.g. solar) to their BTSs as a way to decentralize the power distribution system.

The representatives of the Telecom operators expressed the desire to invest in solar PV power assuming that it will not become an extra burden since their core business is telecommunication. They wish that private individuals would take up the supply of solar PV power for their BTS. According to the views expressed by the participants, collaborations could create a powerful collective vision that could generate change and eventually help overcome the constraints. Two of the participants also proposed that stakeholders should commission independent studies into renewable energy to dispel any technical barrier to its utilization.

A representative we interviewed expressed the importance of a dynamic renewable energy association that could be influential in the national energy policy of the country. He said, “what we need now is renewable energy policy …there is a need for action that can insulate politicians from renewable energy issues”. The stakeholders believe that effective collaborations will garner public support and can be a vehicle for change. This change can remove the restrictions on renewable energy and provide access to the national grid. There was a suggestion from some participants asking for innovative services and products from the renewable energy companies. They stated that this service should be tailored towards organizations such as telecom and ICT in order to reduce the doubts about the technology.

For example, one of the participants had 20 years of working experience as a Telecom power technician. He used his renewable energy work experience to justify the limitations of the technology. This technician has extensive experience and could be used to train other technicians. Since the solar industry is new and emerging, the stakeholders that were interviewed expressed the desire for simple installation tools and the development of machinery to fabricate parts of the installation components.

6.9 Conclusion

The chapter has discussed the various challenges that currently are draw back to ICT and electricity production and acceptance of solar PV and Wind energy in Ghana. Currently, power generation and distribution in Ghana is centralized and comes from the use of light crude oil, natural gas and hydropower, as its primary sources. The chapter reveals that policy, regulation, technical and political issues are some of the important strands that is shaping the acceptance of renewable energy (solar PV and Wind energy) in Ghana. There has been some amount of progress in the policy for promoting renewable energy in Ghana in the last few years, but there is room for improvement in order to have a noticeable increase of solar and wind power in the energy mix of Ghana. There are many issues relating to obligatory connection of renewable energy to the national grid, the purchase of volume of electricity generated from renewable sources and tariffs. There are also problems associated with the functioning of the existing instruments and the issues need to be investigated further. There is a lack of clarity and continuity of approach especially with regards to feed-in tariffs. It is therefore recommended that there is a need for:

(i) Obligatory connection of renewable energy with certain capacity to the grid in order to encourage private individuals to generate more electricity to feed the national grid.
(ii) Introduction of feed-in tariffs for solar and wind power.
(iii) Obligatory purchase of electricity from solar and wind sources: - The electricity transmission and distribution companies (GRIDCO and ECG) must purchase the entire volume of electricity generated from solar and wind sources by private individuals.
(iv) Tax incentives: - There should be no import tax and no levy on value added tax on solar and wind energy equipment. Investors should be granted tax holidays in order to promote electricity generation from solar and wind resources in Ghana.

Chapter 7: Potential BTS Demand, HOMER Simulation and Analysis

7.1 Introduction: Overview of Potential BTS Demand, HOMER Simulation and Analysis

This chapter provides explanations on electric power demand of the BTS, design of optimum generation system and analysis of configurations. Based on the results of potential demand, electricity consumption pattern and load curves are modeled. Using the load curves models, an optimum generation systems for the selected BTSs will be configured. HOMER analytical software engineered by the National Renewable Energy Laboratory (NREL) is the tool used in simulation and analysis of results. The software calculates which configurations provide the best option, in terms of cost for supplying electricity to the BTS. HOMER ranks optimal system configurations according to their Net Present Cost (NPC). Sensitivity analyses were also conducted to determine the impact of variations in natural resources, economic or load conditions on the system, such as unanticipated attenuation of solar radiance, increase in electricity consumption or diesel fuel price increase: this help determine which configurations are robust and adaptable to unanticipated variances in model assumptions. It further explains the details of the procedure and results obtained in all three study sites in Ghana.

7.2 Knowledge of Electricity Load for Typical BTS in Ghana

The reliable performance of the Telecom power system depends considerably on the uninterrupted power, long life and safety of the system. Our case studies were conducted in three different geographical locations within Ghana. The target sites are three base transceiver stations (BTS) operating at - 48VDC. The three BTSs belong to Vodafone - Ghana (formerly Ghana Telecom). The BTSs considered in this study are 2G and 3G networks, indoor and outdoor compact fluorescent lights (CFL), computers for maintenances use, fans and air conditioning units for cooling. The load was put into two categories; that is essential and non-essential. Supply to the Telecom equipment which is DC load (transceiver loads) and indoor lights were considered essential while compound lights, fans and air-conditioning units were regarded as non-essential are AC loads. The AC power is converted to DC before serving the Telecom equipment and storage batteries.

This arrangement will ensure reliable power to Telecom loads which are critical for continuous telecom service. In reality, this will minimize the likelihood of power losses in the event of ancillary equipment failure in items such as the converter or battery bank. If ancillary equipment failure does occurs, power from the PV array or wind turbine can be fed directly into the DC sector to ensure the Telecom load is met without reliance on ancillary equipment. The hourly energy consumption for both AC and DC loads for the entire year (8760 hours) once loaded, HOMER creates an average load curve by extrapolating from the text file data to simply calculation.

7.2.1 Assumptions for Equipment Uses

In addition to equipment acceptance rule, there are assumptions for some equipment and appliances.

7.2.1.1 Base Transceiver

Core Base transceiver equipment are always in operation throughout the whole year. During the day, thus between 6am and 9am the load increases gradually to the pick by 11am and falls back gently from 3pm to base load at 9pm.

7.2.1.2 Compact Fluorescent Lights (CFL)

CFL use is different between daytime and nighttime because of sunlight availability. Normally, the sun rises at 6am and sets at 6pm in Ghana throughout the year. For most of the activities at the sites, no CFLs are used during the daytime. However, for activities that demand enhanced visibility, which are undertaking maintenance, we have assumed that 5 CFLs are used and using computer, we have assumed that 1 CFLs is used during the day.

7.2.1.3 Fan and Air Conditioning Unit

Weather conditions affect fan and Air conditioning unit usage. In the dry season, which starts from November to March, the weather is relatively hot compared to the rainy season, which is April to October. Though fans and Air conditioning unit are obviously used in the dry season for cooling, its primary utility in the rainy season is to maintain an ideal temperature for effective Telecom equipment operation(s).

7.2.1.4 Load Curve Generation

Before a load curve was produced, the activity schedule was converted into an hourly schedule. The hourly energy consumption for both AC and DC loads for the entire year 2013 (8760 hours) once loaded, HOMER creates average load curve by extrapolating from the text file data to simply calculation.

The total DC power required is around 58.18kW/day for the Telecom load while air-conditioning unit and other A.C loads power consumption amounts to 27.25kWh/day (see Table 7.1).

Pay load Power	Energy Consumption	Service hours per day
BTS- 48 V DC	49.56kWh/day	24
MDP- 48V DC	8.62kWh/day	24
AC – 230V A.C	27.25kWh/day	24

Table 7. 1 Summary of Electricity Consumption in the Year 2013

The load curves are similar across months with slightly higher consumption during the dry season, when fans and air conditioning unit are used. This is because the schedules of each of the months are similar. Shown below is the load curve generated for April 2013.

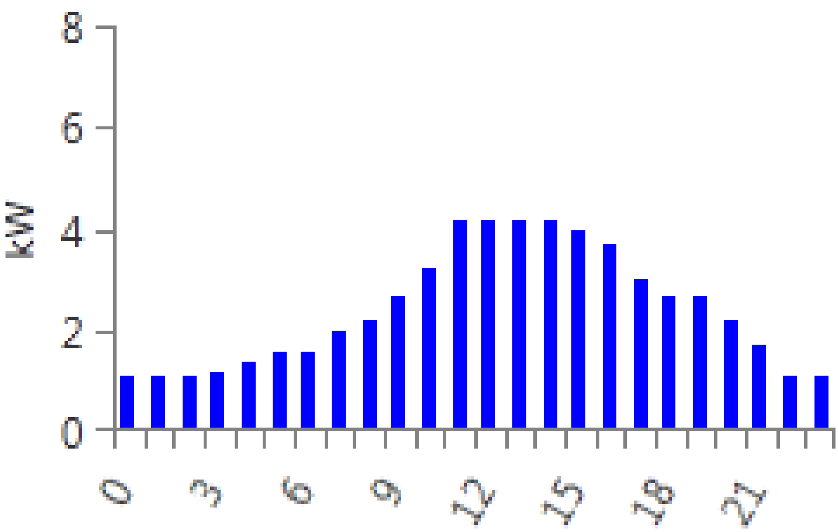

Figure 7. 1 Telecom load (DC) profile of a typical BTS in Ghana

In relation to figure 7.1, the following observations were made: in the load curve above, the time of peak demand varies from 08:30 in the morning to 21:30 in the night when the mobile traffic and temperature increase. The power consumption from

22:30 pm to 06:30 am is considered constant, as the weather becomes mild and phone call rate goes down, but when the random ‘on’ and ‘off’ of the air conditioners is considered, its contribution is shown as small peaks. The time at which the ‘night time load’ ends varies from 05:30pm to 06:30am on market days in some areas and also at weekends. Likewise for the A.C loads, the air-conditioners operates from 06:00 in the morning till 21:00 in the night to ensure favourable temperature for equipment operation.

7.2.1.5 Study Area and Load Profile

The study areas were Kabakaba Hill, Ada-Foah, and Jema. Due to the distance of the cell sites (e.g. usually on top of mountains in isolated areas), grid electricity is not available at Ada-Foah and Jema and these cell sites depends on DEG for their electricity supply.

Also, by the nature of the road networks, it is difficult to transport diesel fuel to the stations in addition to performing routine maintenance on the power generators. Though Kabakaba Hill is within the Ho municipality and therefore has grid electricity supply, the power supply is not reliable, so the standby generator is almost always running.

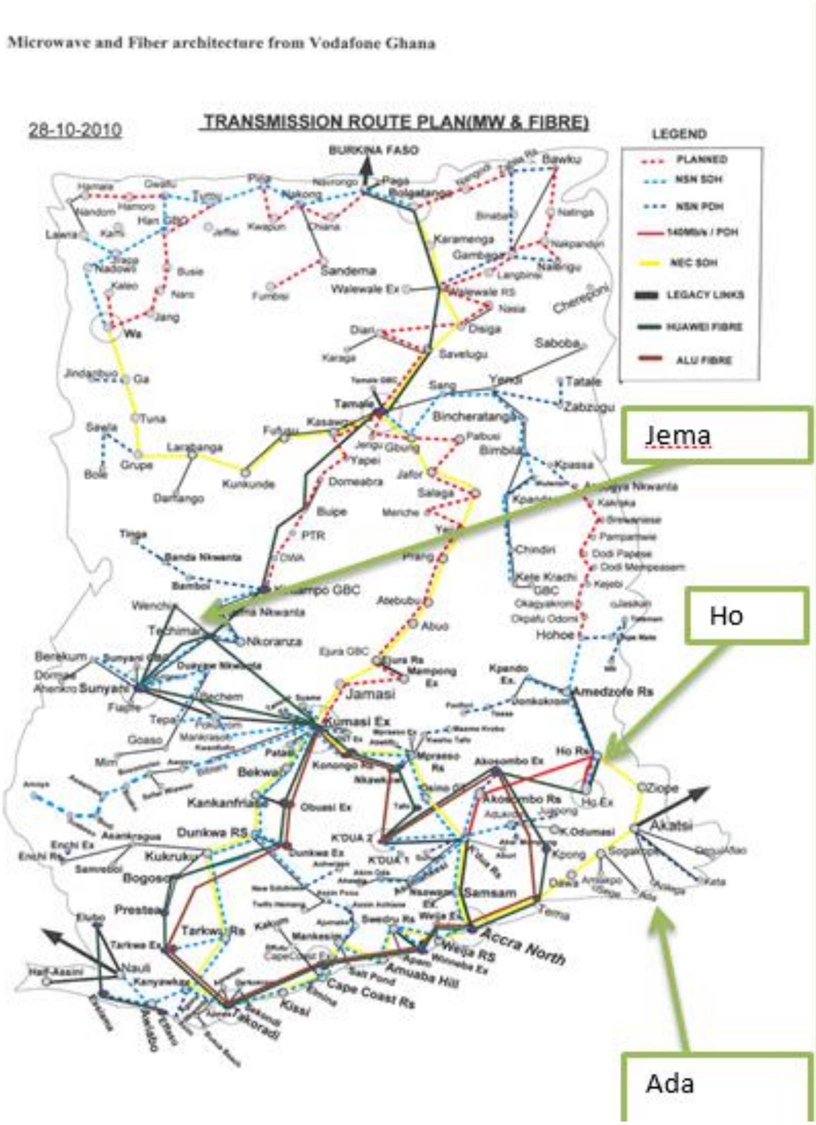

Figure 7. 2 Selected Base Station Locations (i.e. Jema, Ho, & Ada) of the study.

7.3 Design of Hybrid System

This hybrid energy system, consists of three primary functions: power production, energy consumption and storage. Considering the availability of solar and wind resources all over the country, the hybrid system proposed in this study is a combination of solar PV, wind turbine, DEG, Battery bank and converter for effective use and to achieve enough energy storage. This hybrid design illustrates (Figure 7.3) the relationship between the components.

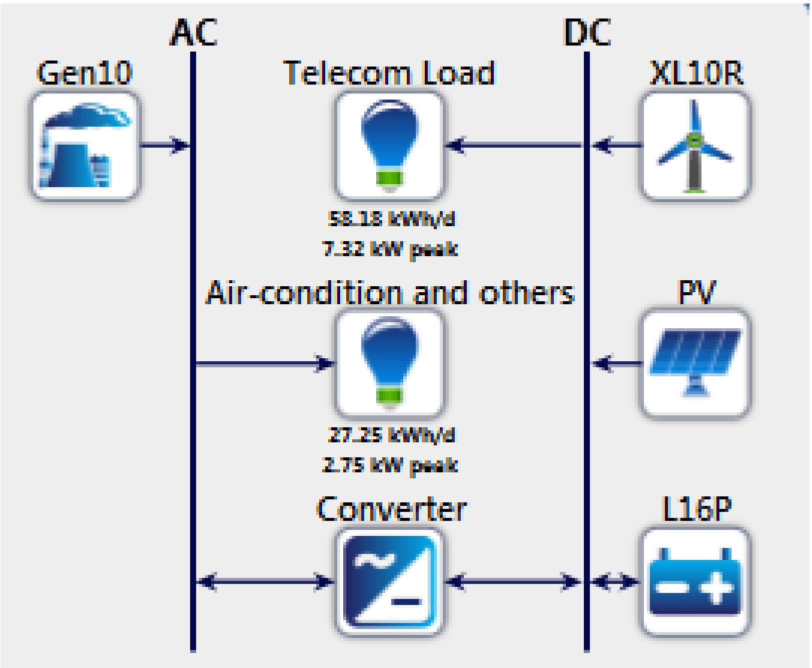

Figure 7. 3 Screenshot of a Schematic Diagram of Hybrid Power Configurations Considered.

Source: NREL, US Department of Energy (HOMER 2011)

HOMER simulation is comprised of alternating current (AC) loads and direct current (DC) loads. The PV array and wind turbine produce DC power that can be fed directly into the DC load without conversion to AC. Excess energy produced by either the PV array or wind turbine that exceeds DC and AC load requirements is stored in the battery bank. If the DC load requirements exceeds the energy production of both the PV array and the wind turbine, stored energy in the battery bank is directly fed into the DC load.

In order to take care of AC energy load needs, the DC energy generated can be converted from DC to AC with the help of the converter which allows for energy transformation from DC to AC, or vice versa. Because the PV array and the wind turbine do not produce AC energy, the converter should transform just enough required energy for AC needs in order to minimize conversion losses.

The final system configuration will be decided after performing the optimization.

In order to achieve an optimal number of system components, HOMER allows multiple values to be entered. These user-supplied values shown in a table 7.2 depicts "search space" (see Table 7.2). A total of 278 system configurations are possible. During simulation, HOMER searches through this space to determine the optimal configuration.

PV array (kW)	BWC Excel-R Wind turbine (quantity)	DEG (kW)	Trojan Battery (quantity)	Converter (kW)
5	1	10	8	10
10	2	15	16	
15	3	18	24	
		20	36	

Table 7. 2 System Search Space

Hybrid systems which use diesel fuel do not necessarily require energy storage for effective operations; however, pure wind and solar installations can have significant energy storage requirements. The only energy storage suitable for the load size in these BTSs is usually batteries. There are other options, such as fly wheels and hydrogen, but neither of them store large amounts of energy and are considerably expensive. Therefore, to minimize fuel consumption of the back-up diesel generator, power for charging battery banks has to be provided from the photovoltaic cell. The energy for battery charging can also be provided from the wind generator.

7.4 Diesel Engine Generator (DEG)

One of the requirements of a DEG in a hybrid power system is to ensure uninterrupted power supply. DEGs are also supposed to provide optimal power while consuming minimal fuel and produce little carbon dioxide emissions. A 10, 15, 18 and 20kVA DEGs were considered as a primary power generation option for the BTS sites in our study because the power source available from wind turbines and solar PVs did not always produce sufficient power. Therefore, DEGs assist in increasing the reliability of power supply at the station. We evaluated the capacity, the capital cost, replacement parts cost, the operating life span and other operation and maintenance expenditure. In the model, all the generators have an expected duration of 15,000 operating hours and operate with a minimum load ratio of 25%. It was assumed that all generators have the same fuel efficiency curve, with an interception coefficient of 1.09L/hr/kW and a slope of 0.25 L/hr/kW. It implies that the fuel efficiency for the generator is about 32% at peak load. While this is a reasonable expectation for larger generators, many smaller generators show somewhat lower fuel efficiencies (Hamm, 2007).

7.5 Diesel Fuel for Generator characteristics

Generators were modeled using diesel fuel, as it is the only fuel that could be used to run the existing generator sets. Therefore, diesel fuel cost are the primary expense when operating DEGs. At the time of the survey, the price of diesel fuel in Ghana was roughly equivalent to U.S. $1.09 per litre (in May 2014).

Fuel Cost ($)	**Fuel interception coefficient (L/hr/kW)**	**Fuel slope (L/hr/kW)**	**Fuel Density (kg/m^3)**	**Carbon Content %**	**Sulphur content %**
1.09	**1.09**	**0.25**	**820**	**88**	**0.33**

Table 7. 3 Diesel Fuel Characteristics

7.6 Energy Storage (Battery Bank)

Batteries play significant role in the long term success of renewable energy projects. Within the expected life span of 25 years for renewable energy system, it is necessary to replace batteries few times over this period. The life span of batteries depends on several factors, including brand, specification, ambient temperature as well as discharge regime. Based on these factors, average anticipated life of the batteries can vary between three (3) to eight (8) years. HOMER software projects the life span of the batteries used in the simulation to be 7.8 years. This requires batteries to be replaced at most three times over 25 years in anticipation.

7.6.1 Battery specification and cost

The study utilized 360Ah deep cycle batteries. The HOMER software provides a number of preloaded batteries available for modeling purpose. From these choices, Trojan 1kWh lead acid deep cycle battery with a nominal voltage of 6V and a nominal capacity of 360 ampere hour (AH) were suitable to be used for the solar and wind power systems was selected as appropriate for our study modeling. The capital cost of one battery was U.S. $300 dollars and had a float life span of 10 years. The replacement cost of this battery was U.S. $300 dollars with the operation and maintenance cost being U.S. $20 per year. A detail listing of this battery' specification is provided in table 7.4 below. Trojan deep cycle DC battery cost assumption for batteries, were taken from capital cost price list of the manufacturer (see appendix).

The relation between the battery capacities in AH and the discharge current in ampere (A) are shown in Figure 7.4. The relationship between the cycles of failure and the depth of discharge is also shown in Figure 7.5.

Quantity	Capital cost ($)	Replacement cost ($)	Operation & Maintenance ($)
1	300	300	10

Table 7. 4 Trojan deep cycle battery

Battery Specification	
Nominal Capacity	360 AH
Nominal Volt	6 V
Efficiency	80 %
Min. state of charge	40 %
Float Life	10 years
Max. charge rate	1A/AH
Max. charge current	16.666 A
Suggested Lifetime throughput	818 KWh
Max. capacity	84 AH
Capacity ratio	0.403
Rate constant	0.827/hr

Table 7. 5 Trojan deep cycle battery specification

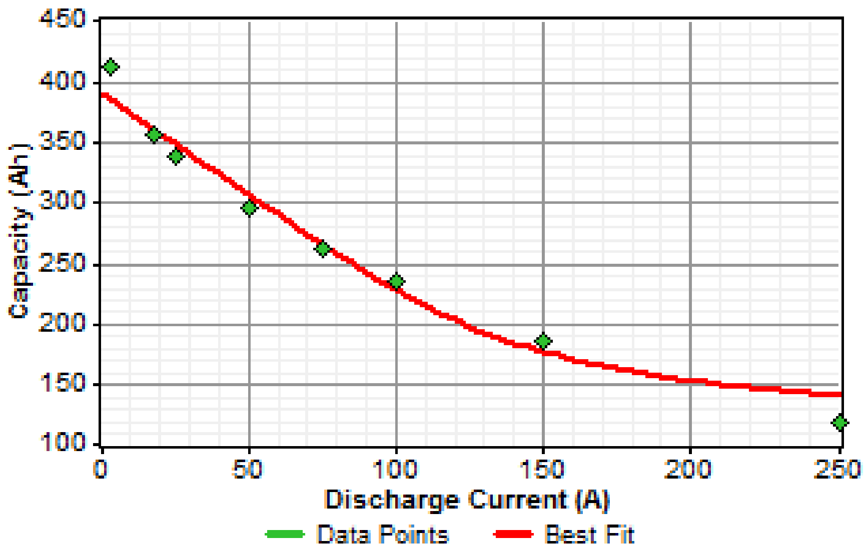

Figure 7. 4 The relation between the battery capacities in ampere hour (AH).

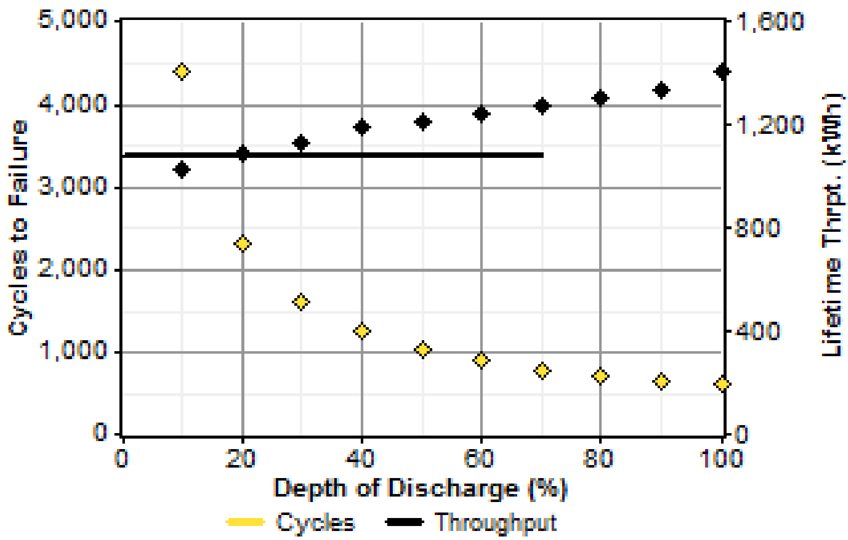

Figure 7. 5 The Relation between the Discharge Current in Ampere (A).

7.7 Power Converter

A converter is part of the power system that comprises both of a rectifier and inverter. The rectifier converts the alternating current (AC) from the DEG to direct current (DC) as required to power the Telecom equipment. The inverter ensures stable direct current (DC) from the solar and wind sources is converted to alternating current (AC). The converter allows the storing of the excess energy produced by the wind turbines or solar PV arrays to be fed directly to the DC loads or batteries.

We were mindful of the capacity, cost, operation, maintenance cost and energy efficiency of the converter and so, considered 8kW with a capital cost of U.S. $8000 and operation and maintenance cost of U.S. $100 per year. The inverter input has an efficiency of 90% with a lifetime of 15 years while the capacity of the rectifier relative to the inverter is 100% with 85% efficiency.

7.8 Solar Photovoltaic System

Though solar resource data were gathered from the Energy Commission of Ghana, Kwame Nkrumah University of Science and Technology and the Ghana Meteorological Service, solar resources can also be imported directly from the National Aeronautics and Space Administration (NASA, USA), Surface Meteorology and Solar Energy data base by entering the global positioning system (GPS) coordinates. Using the coordinates of Ho, Ada-Foah and Jema, we obtained an annual solar radiation of 58.18kWh/d, with monthly solar radiation showing patterns of consistency at all study locations (Figures 7.6, 7.7 & 7.8).

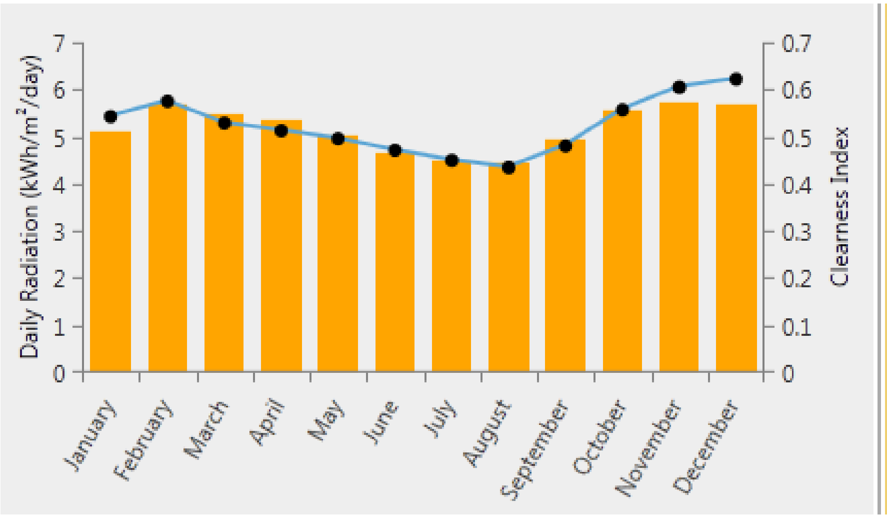

Figure 7. 6 Annual Solar Radiation for Ho.

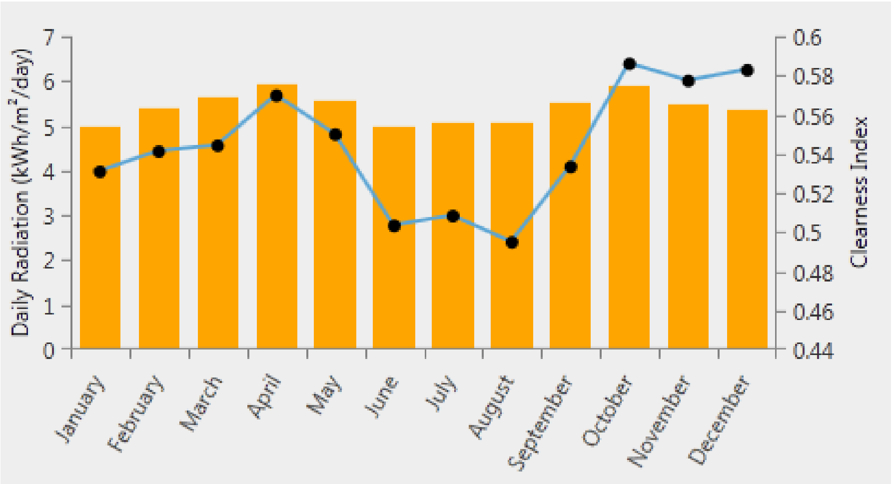

Figure 7. 7 Annual Solar Radiation for Ada-Foah.

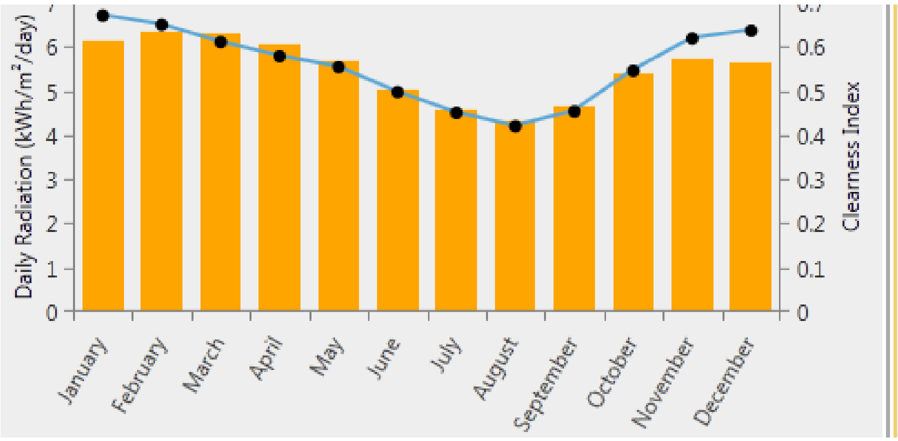

Figure 7. 8 Annual Solar Radiation for Jema.

The solar PV modules used in the proposed system are assumed to be a mono-crystalline silicon solar module, which is less than U.S. $1.00 per watt excluding shipping, training and installation which will be added to the capital costs. The solar PV modules life span of twenty-five (25) years is considered industrial standard, working with a PV de-rating factor of 80%. All panels are installed with an azimuth angle of 180°. Ground reflectance is assumed to be 20% and a horizontal axis monthly adjustment is considered to increase the effectiveness of a solar PV unit. Operation and maintenance costs are somehow difficult to assess, but are considered minimal (See table 7.6).

Qty (KW)	Capital cost ($)	Replacement cost ($)	O&M ($)	Life span (yr)	Derating factor (%)	Slope degree	Azimuth	Ground reflection (%)
5	3,835.62	3,835.62	100	25	80	9.47	20	20
10	7,671.23	7,671.23	100	25				
15	11,506.85	11,506.85	100	25				

Table 7. 6 Solar PV Constraints

Because of the ambient temperature and accumulation of dust, due to occasional mild to heavy dust storm which is a climatic phenomenon that prevails in the country during the harmattan season, it negatively impact on solar radiance therefore a conservative value of 88 was decided as derating factor. The derating factor accounts for the losses in the conversion of solar irradiance to energy by the PV array. The cardinal direction of the panel and the slope (angle relative to horizontal) at which the PV array is mounted are calculated by the software. The slope default setting of 9.47 corresponding approximately to the country Ghana.

7.9 Wind Source

Using wind resource data gathered from the Energy Commission of Ghana and the Ghana Meteorological Service, BWC Excel-R wind turbines manufactured from Bergey Wind Power Company (USA) were considered in this simulation. The turbine was rated at 10 kW DC and cost U.S. $22,650. A hub height of 20 m was considered and turbine lifespan was taken as 25 years. The operation and maintenance are estimated to be U.S. $500 per year. Figure 7.9 shows the power curve of these 10 kW units. Figure 7.10, 7.11 and 7.12 also show the wind resources from Kabakaba Hill, Ada-Foah and Jema, respectively.

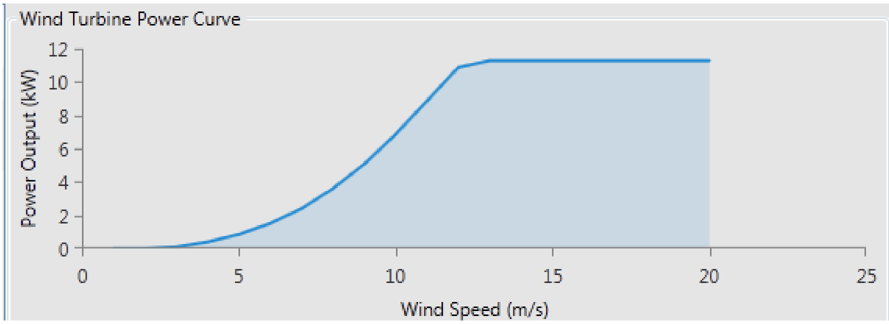

Figure 7. 9 Characteristic power curves of 10 kW wind turbine units from simulation.

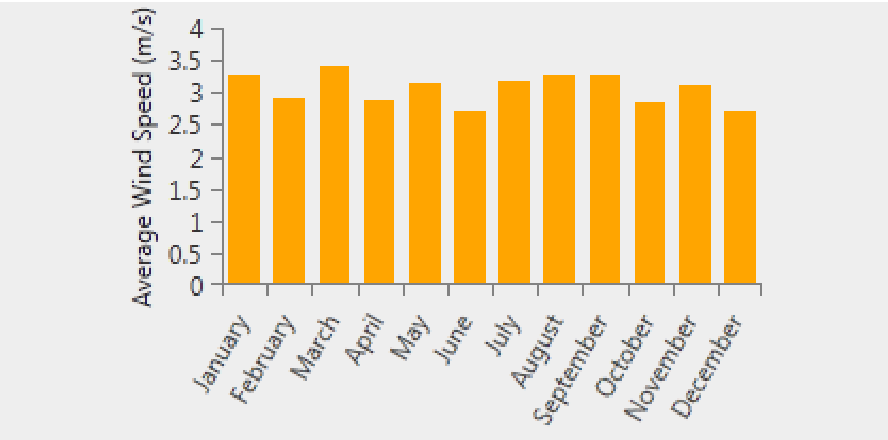

Figure 7. 10 Figure Monthly average wind speed for Ho.

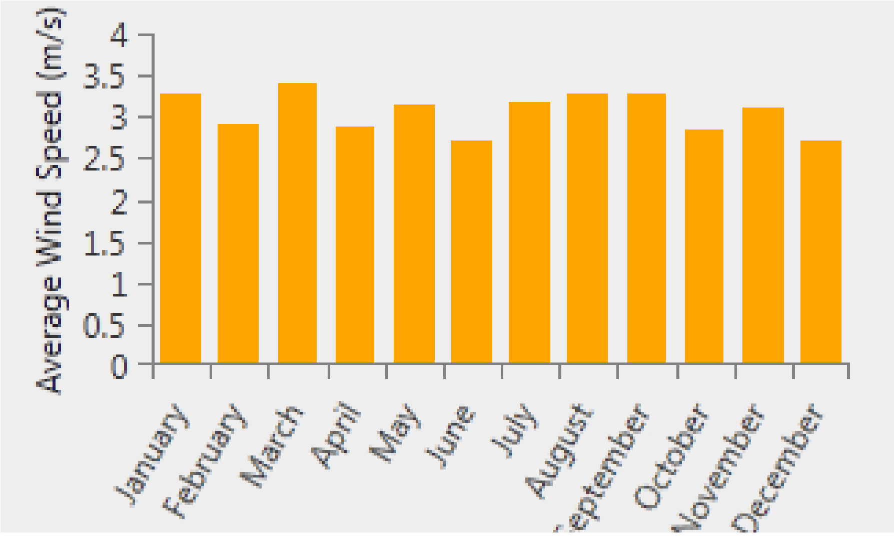

Figure 7. 11 Monthly average wind speed for Ada-Foah

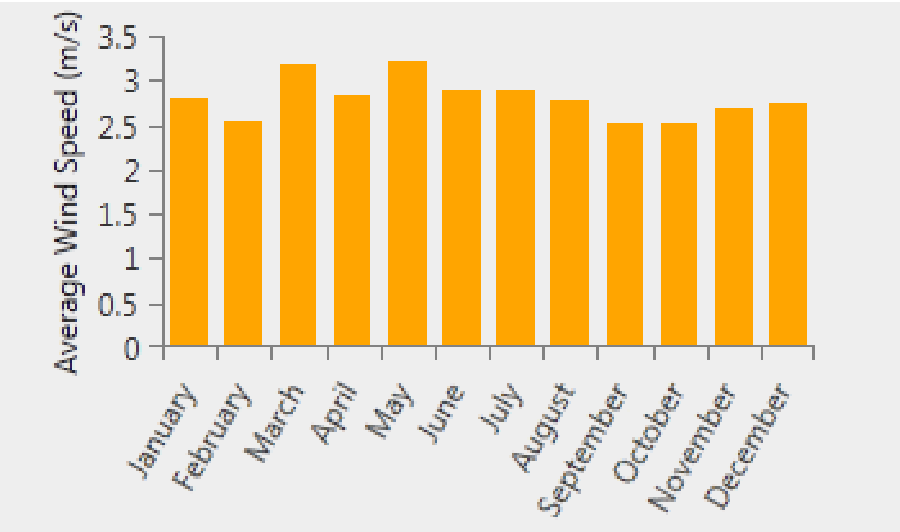

Figure 7. 12 Monthly average wind speed for Jema.

7.10 Economic Input

Ghana's economy has not been very stable for many years. Interest rates vary considerably, ranging between 8% and 11%. This rate can significantly impact on optimal system configuration of modelling, because the software ranks each system according to its Net Present Cost. The wide range of rates of Ghana was considered in the sensitivity analysis. The total cost is distributed over a 25 year project lifetime, which is typical for renewable energy projects. It is somehow difficult to actually assess the exact operation and maintenance costs but is very crucial for the success of projects. However, the fascinating thing about renewable energy is that, they are maintenance free as long as routine service is conducted to ensure that the system is functioning optimally. Therefore, “system fixed Operation and maintenance costs’’ were designed to provide sufficient funds to manage and maintain the BTSs. Because simulation assumptions were overly optimistic, sensitivity analysis was conducted to determine how the entire lifetime of system costs would increase.

7.11 Other Constraints

HOMER has capacity shortage factor which permits the modeler to specify the maximum percentage of time the demand can go unmet. As the capacity shortage factor approaches zero, the system becomes more reliable, but at the same time, the system cost increases since more investment in the equipment will be necessary to meet that requirement. HOMER system is designed to be more flexible and more reliable than the national grid, which is prone to fluctuations and outages due to arbitrary increasing demand and archaic infrastructure. A 10% capacity shortage factor was used as reference, but HOMER software often optimizes design systems that are more reliable than what is required by this constraints. The software permits modeler to specify a minimum renewable fraction which enable the model to determine the best energy mix generation. Since the load profile is based on hourly data, the operating reserve will compensate for any unanticipated load increase in energy production. But in case the operating reserve is over estimated, the consequence will be an increase in the capital cost which might be unreasonable and unjustifiable. Therefore it is not necessary to apply operating reserve that is greater than the default setting of the software.

Other constraints	
Max. Annual capacity shortage	10 %
Min. Renewable fraction	0%
Operating reserve for hourly load	10%
Operating reserve for annual peak load	0%
Operating reserve of Solar Power	25%
Operating reserve of wind power	50%

Table 7. 7 Economic constraints (Source-NREL/2011)

7.12 Simulation Results and Analysis

The input parameters and system constraints were used in simulating the hybrid system and performing the optimization process and sensitivity analysis. The HOMER determines the optimal system by selecting the suitable system configuration based on the sensitivity parameters such as wind speed, diesel price and maximum annual shortage. It determines the NPC and the COE from the installation and operation of different power generation technologies over the 25 year life span. For each configuration, the NPC, the system capacity mix and the energy mix were analyzed.

The sensitivity variables were wind speed, solar radiation and diesel price. These variables are beyond the control of the designer/modeler. HOMER sensitivity analysis assesses the effect that these variables can have on the configuration.

7.12.1 Optimization Results

Table 7.8, 7.9 and 7.10 ranks feasible system configurations from the lowest net present cost (NPC) to the highest net present cost for conditions at the three sites, thus Kabakaba Hill , Jema and Ada-Foah respectively. HOMER software is designed to rank feasible systems by NPC as opposed to the average cost of electricity (COE). The designers of the software argue that it is a much more reliable and less biased metric for making these determinations, because a conventional mathematical formula does not require a number of illogical assumptions, whereas the COE does require several assumptions.

7.12.2 Economic Comparisons

The required investment for the selected power system is compared between the current power supply and the base stations loads. The existing diesel system being used has low initial capital cost and high operating costs. But, the hybrid systems selected for this simulation has a higher initial cost and a low operational cost. In all cases, money will be spent on building, installing and operating the systems.

7.12.3 The Cost of Energy from National Grid

The three studied BTSs in this thesis are in different remote towns/villages, thus it was difficult to have a common cost for the extension of the electric grid supply. However, the annual cost involves the towers, conductors, insulators, earthing electrodes, isolator switches, transformers, distribution boards and other components and parts. It is well known that the annual running cost of electricity may be less than the PV/DEG system (GRIDCo. Ghana, 2010), but we must consider the unavailability and/or poor electricity supply to the BTSs. Thus, the annual running cost = Cost of energy + cost of energy losses + maintenance cost.

7.12.4 Security of Solar Energy Source

While the initial cost of solar PV is higher than the DEG, it should be noted that solar energy is renewable and the prices are rapidly declining as technology innovation improves. Every dollar which is invested in solar PV will help to reduce our dependence on foreign energy sources and increase our political and economic independence.

7.13 Simulation Results for Kabakaba Hill (HO)

7.13.1 The Final System Configuration Selected for Kabakaba Hill Base Station

Under 100% annual load requirement, the simulation results indicates, PV/DEG with battery storage as the optimal configuration at low wind speed. However, at high wind speed and an increase in diesel price, the PV/wind turbine system becomes more feasible. Table 7.8 shows the ranking of the most feasible system for a fixed diesel price of U.S. $1. Per litre and an average wind speed of 3.06 meter per second. Considering the NPC, the most feasible configuration is made up of a 10 kW PV array, 10 kW wind turbine, a 10 kW DEG, with 36 pieces of 360AH storage batteries and 8 kW converter. This is also the optimal configuration when considering the COE as the determining criteria. In this configuration, the solar energy charges the battery and the DEG operates only to supply power to the loads when the battery power is minimal. The NPC of this configuration is U.S. $228,103 and COE is U.S. $0.566. Figure 7.13 shows the total contribution to the total electricity generated by individual system components. The PV system has a capacity factor of 17.4% and supplies 42.14% of the annual electricity production. The DEG has an overall efficiency of 44.06%, operates for 2174 hour per annum, and has capacity factor of 18.24%. With the increase in future diesel price and lower PV module costs, a higher contribution from the renewable component can be expected.

Architecture						Cost				System	Gen10	
PV (kW)	XL10R (qty)	Gen10 (kW)	L16P (qty)	Converter (kW)	Dispatch	COE ($/kWh)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)	Fuel (L)	Hours
10.0	1	10	36	8	CC	$0.566	$228,103	$11,731	$76,450	48.8	5,613	2,174
10.0	1	10	16	8	CC	$0.593	$239,009	$13,038	$70,450	45.3	6,708	3,809
10.0	2	10	36	8	CC	$0.593	$239,130	$10,832	$99,100	61.2	4,349	1,846
10.0	1	10	24	8	CC	$0.595	$240,009	$12,931	$72,850	46	6,381	3,264
10.0	2	10	24	8	CC	$0.613	$247,048	$11,723	$95,500	57.2	5,095	2,670
5.0	1	10	36	8	CC	$0.616	$248,477	$14,468	$61,450	24.7	8,152	3,000
5.0	1	10	24	8	CC	$0.618	$249,121	$14,796	$57,850	25.1	8,357	3,489
10.0	2	10	16	8	CC	$0.624	$251,487	$12,252	$93,100	54.3	5,680	3,351

Table 7. 8 Screenshot of the optimization table ranking for Kabakaba Hill.

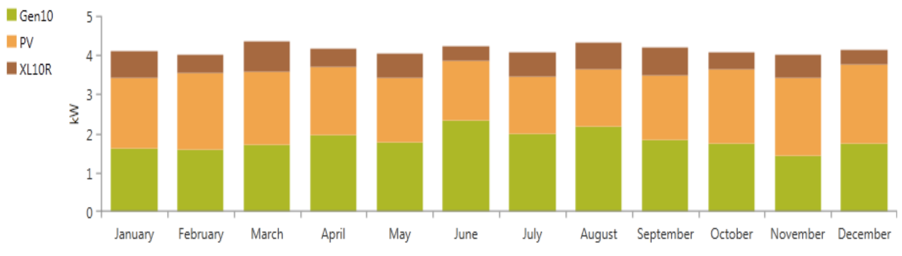

Figure 7. 13 Monthly Average Electric Productions from the three sources Considered for Kabakaba Hill from Simulation.

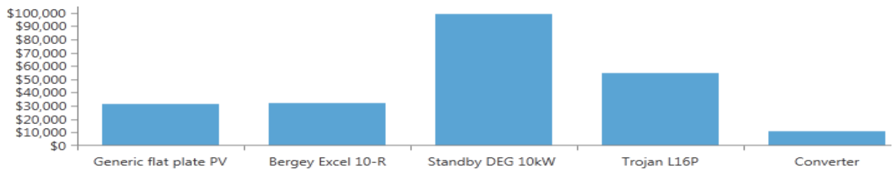

Figure 7. 14 Life Time Costs of Different Components for Kabakaba Hill.

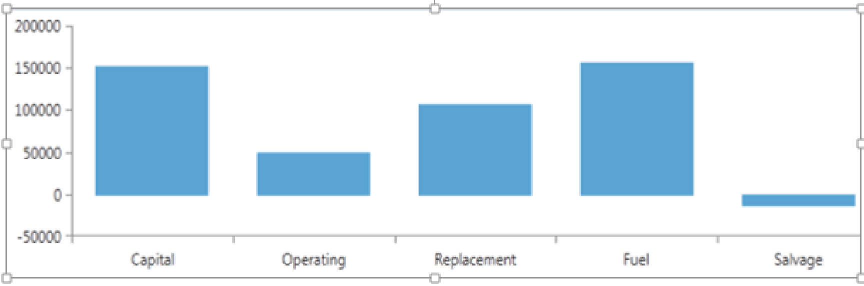

Figure 7. 15 Categorized Lifetime Costs of the Final Selected System to Supply the Load from Simulation.

7.13.2 Cost of Energy Produced from PV/DEG Hybrid System

The life cycle cost method is the most largely used to evaluate the financial viability of a PV and wind energy system, which is the sum of the capital cost and the present value of all components used for the system design. The cost PV/DEG hybrid chosen for the BTSs, include the capital cost (COPEX), operation and maintenance cost and replacement cost. For the chosen systems, the capital cost is high, but the fuel consumption, maintenance and replacement costs are low.

The life cycle cost of the PV/DEG/WIND hybrid assumes the following:

1. The lifetime of all items is considered for 25 years, except the batteries which are considered for 10 years.
2. The interest rate is about 11%.

The final outcome has the following characteristics: NPC and COE were U.S. $228,103 and U.S. $0.566/kWh, respectively, were lower than any diesel-only systems that could meet the same load demand. Out of the total annual electricity production of 36,266 units (kWh/Yr), solar PV supply 42.14% while DEG supplies 44.06%. The DEG runs for 2174 hours per year and produces 14781 kg of CO_2 which is minimal when compared to the diesel-only systems which will run for 8760 hours per year and will produce approximately 59559.14 kg of CO_2. Therefore, an annual CO_2 emission reduction of 44778.14 kg will be achieved.

7.14 Simulation Results for Ada - Foah

7.14.1 The Final System Configuration Selected for Ada – Foah Base Station

The simulation in Ada-Foah BTS was similar to what was previously done in Kabakaba Hill. However, due to the changes in geographical location and weather conditions, the results differ. Because the area has high wind speed, electric power production is mainly between solar and wind source i.e. 34.82% solar and 55.8 % wind with the standby generator producing only 9.37%. By using all generating sources, the necessary technical details from the simulation are shown in the schematic diagram in Figure 7.16. Table 7.9 shows a summary of the life time costs of different configurations, as well as capital cost and the overtime costs of different configurations for a fixed diesel price of U.S. $1.09/l and an average wind speed of 5.52m/s.

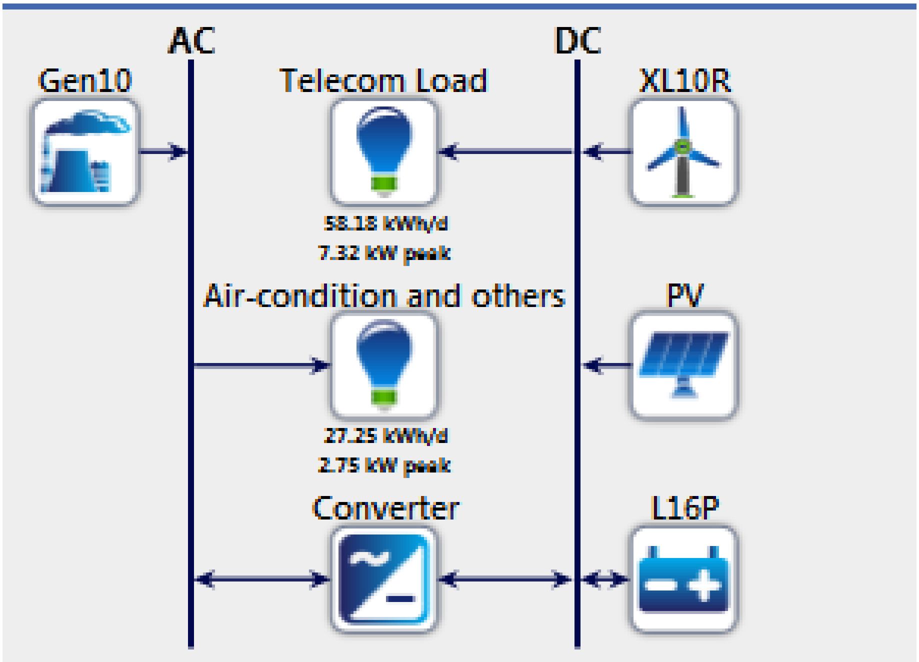

Figure 7. 16 Screenshot of schematic diagram of Ada Foah system configuration.

Architecture						Cost				System	Gen10	
PV (kW)	XL10R (qty)	Gen10 (kW)	L16P (qty)	Converter (kW)	Dispatch	COE ($/kWh)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)	Fuel (L)	Hours
10.0	1	10	36	8	CC	$0.370	$149,186	$5,626	$76,450	86.3	1,576	736
10.0	1	10	24	8	CC	$0.386	$155,485	$6,392	$72,850	81.5	2,261	1,279
10.0	1	15	36	8	CC	$0.390	$157,361	$6,066	$78,950	85.5	1,840	756
10.0	2	10	36	8	CC	$0.392	$158,075	$4,562	$99,100	94.9	605	306
5.0	2	10	36	8	CC	$0.393	$158,584	$5,762	$84,100	88	1,357	591
10.0	2	10	24	8	CC	$0.398	$160,457	$5,025	$95,500	91.3	1,084	645
10.0	2	15	36	8	CC	$0.402	$161,968	$4,670	$101,600	94.6	691	293
10.0	1	18	36	8	CC	$0.403	$162,644	$6,358	$80,450	84.9	2,011	767

Table 7. 9 Screenshot of the summary of lifetime costs for Ada-Foah BTS from simulation.

According to table 7.9, the most feasible configuration is made up of a 10 kW solar PV panel, 10 kW wind turbine with 36 Trojan (2V) battery storage. The final outcome has NPC of this configuration as U.S. $149,186 and COE as U.S. $0.37.

The total annual electricity production is 45,617 kWh comprising 15,885 kWh/yr of solar (34.82%), 25,456 kWh/yr of wind (55.8%) and 4276 kWh/yr of DEG (9.37%). The annual operational cost is U.S. $5,626 with 4150.7kg/yr of CO_2 emission. Compared to the diesel-only systems, the generator will work for 8760 hours annually. There is a fuel savings of 17,184 litres of diesel per year and an annual CO_2 emission reduction of 45,251.6 kg/year. Figure 7.17 shows the monthly average electric production from the sources selected.

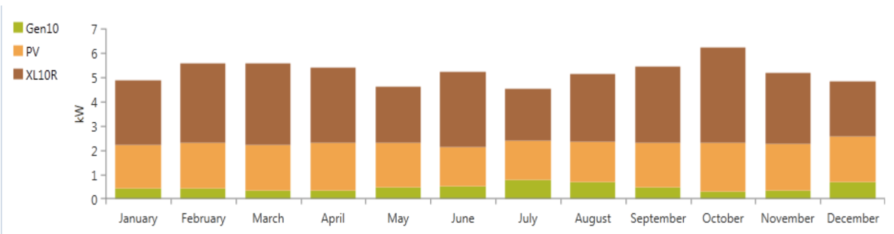

Figure 7. 17 Monthly Average Electric Production from the three sources considered for Ada-Foah BTS from simulation.

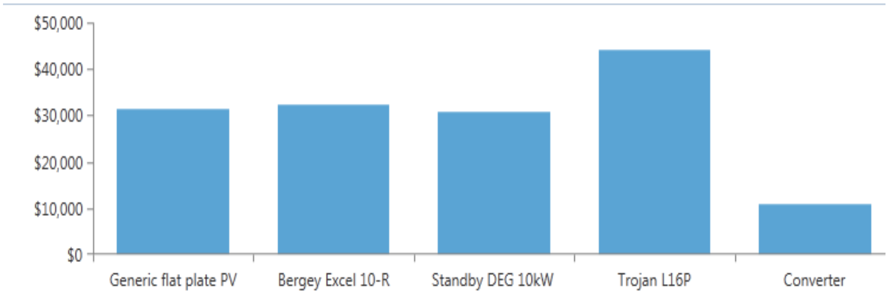

Figure 7. 18 Lifetime Costs of Different Components for Ada-Foah BTS from Simulation.

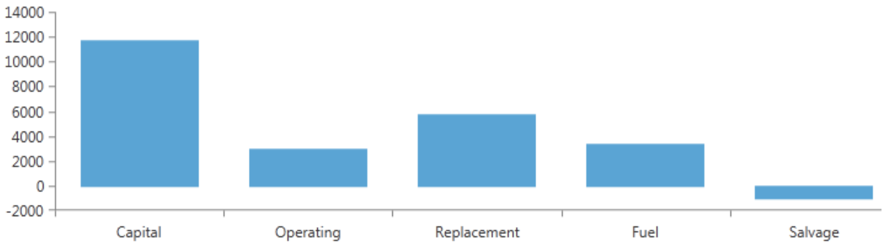

Figure 7. 19 Categorized lifetime costs of the final selected system for Ada-Foah BTS from simulation.

7.14.2 Configuration for Ada–Foah Base Second Operator' Simulation

In order to make our findings more general, the load of another network operator was used for simulation at Ada-Foah. This operator is also using 2 and 3G for their operation, but because of less traffic on their network, their load is a little less than the first operator. Also they are using a smaller capacity air conditioning unit for space cooling. The Telecom load is about 54.18 kWh/d and other AC loads is about 18.75 kWh/d (see appendix E). The cost of energy (COE) and the net present cost (NPC) of the system for the second operator is within the same range as the first operator.

Also, based on free air equipment cooling being research by Telecom equipment manufacturers and advocated by different interest groups (Edler & Lundberg, 2004) (Gonzalez-Brevis, et al., 2011), HOMER simulation is also run solely on Telecom load at Ada-Foah. The results shows that energy supply from the configuration is very reliable and adequate for the entire load with a very low net present cost (NPC, US$ 77,881) for the selected system configuration. It also show less cost of energy (COE, US$ 0.319) with no diesel fuel use. (Please see appendix G).

7.15 Simulation Results for Jema Base Station

7.15.1 The Final System Configuration Selected for Jema Base Station

The simulation which took place in Jema BTS in the Northern sector of Ghana was similar to what was done earlier in the Kabakaba Hill and Ada-Foah BTSs. However, the climate in this area is quite different. Jema area is quite humid with low wind speed, therefore the simulation results are slightly different. By using all generating sources, the relevant technical details from the simulation are shown in table 7.10. The table shows a summary of the lifetime costs of different configurations as well as the capital overtime costs of different configurations.

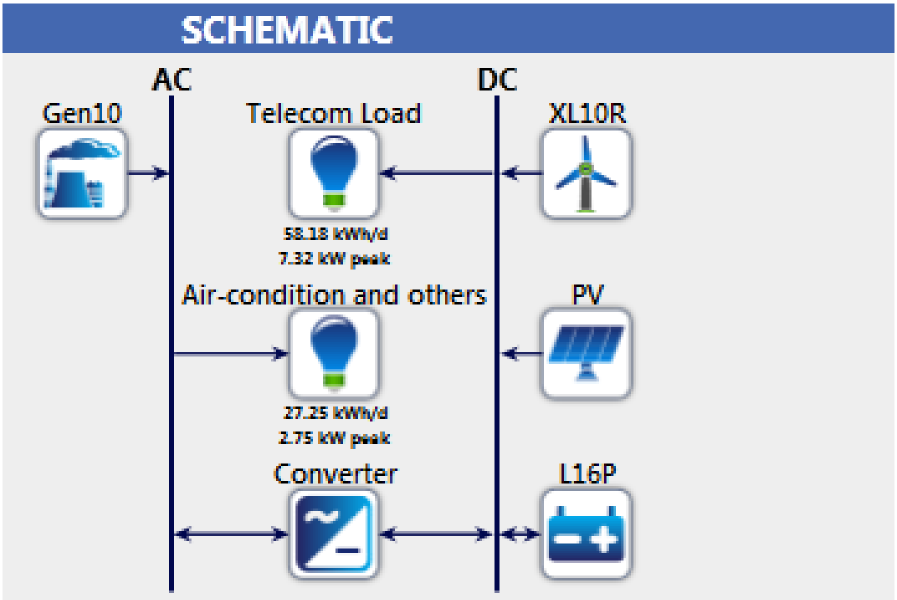

Figure 7. 20 Screenshot of the schematic diagram for the Jema BTS simulation.

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Optimization Cases: Left Double Click on simulation to examine details.

Architecture						Cost				System	Gen10	
PV (kW)	XL10R (qty)	Gen10 (kW)	L16P (qty)	Converter (kW)	Dispatch	COE ($/kWh)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)	Fuel (L)	Hours
10.0	1	10	36	8	CC	$0.580	$233,807	$12,172	$76,450	48.1	5,776	2,381
10.0	1	10	16	8	CC	$0.606	$244,311	$13,448	$70,450	44.2	6,918	4,041
10.0	2	10	36	8	CC	$0.608	$245,118	$11,295	$99,100	58.5	4,650	1,979
10.0	1	10	24	8	CC	$0.609	$245,426	$13,350	$72,850	45.1	6,579	3,497
5.0	1	10	36	8	CC	$0.630	$254,093	$14,902	$61,450	22.4	8,431	3,155
5.0	1	10	24	8	CC	$0.633	$255,078	$15,256	$57,850	22.8	8,629	3,643
10.0	2	10	24	8	CC	$0.636	$256,290	$12,438	$95,500	54.5	5,492	2,980
10.0	1	10	8	8	CC	$0.637	$256,839	$14,604	$68,050	38.1	8,096	5,365

Table 7. 10 Summary of lifetime costs for Jema BTS from simulation.

The selected configuration for the Jema BTS also uses a minimum amount of renewable energy sources together with the DEG as a stand-by for bad weather. The final outcome of simulation for Jema site has the following characteristics: NPC and COE were U.S. $233,807 and U.S. $0.58/kWh, respectively, lower than any other configuration that could supply the same load demand. From Table 7.10, the NPC for PV/WIND/DEG combination is high, because of low wind speed availability. Electricity production at this site comes from the use of DEG and solar sources.

Out of the total annual 36,265 kWh/year of electricity production, the DEG produces 44.87% and the solar produces 44.67%. Only 10.46% is produced from wind energy source. Figure 7.21 shows the details of monthly average of electricity production while figure 7.22 and 7.23 shows lifetime costs of the project for Jema site.

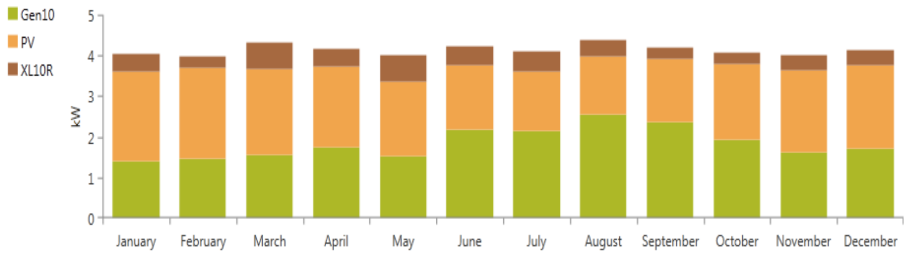

Figure 7. 21 Monthly Average Electric Productions from the three sources considered for the Jema BTS from simulation.

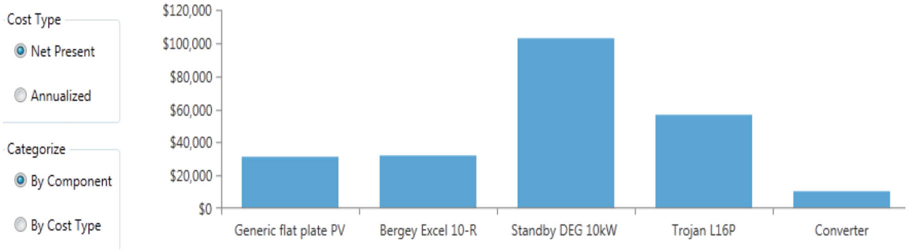

Figure 7. 22 Lifetime costs of components for Jema BTS from simulation.

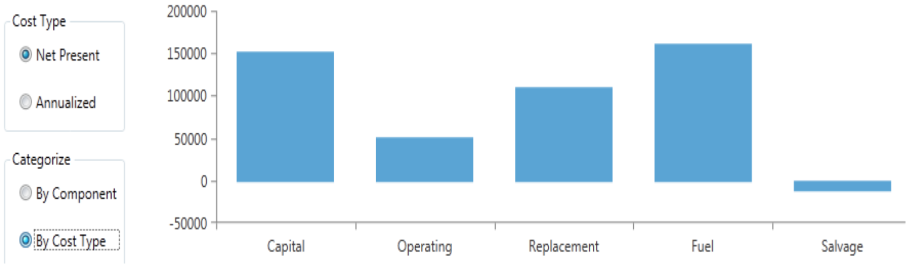

Figure 7. 23 Capital Cost and Long-term Cost of the selected system components for Jema BTS from simulation.

7.16 Conclusion

The chapter discusses knowledge of electricity and load pattern for a typical 2G network in Ghana. The chapter used HOMER simulation to ascertain technical feasibility and economic viability of renewable energy application at three different BTS in Ghana. Data used for the design and simulation were taken from the northern sector, the central part of the country and along the gulf of guinea. The northern sector has severe and humid weather while the central and coastal parts have moderate wind speed. Different capacities of DEGs, solar PVs, wind turbines, converter, batteries and fuel price were chosen as input for the HOMER simulation.

The simulation process considered all possible power system configurations to determine the technical feasibility of all combinations. It also takes cognizance of the total cost of installation and operation of the system throughout the life span of the project. In the optimization process, the model simulates the different configurations and proposes the most appropriate and technically feasible configuration that could yield the lowest life cycle cost, bearing in mind technical and financial constraints within the local area. The storage battery autonomy analysis were based on the charging cycle since it prolongs the battery autonomy by maintaining the charged state. The storage capacity is a fraction of the entire load and reserve (Dufo-Lopez, Bernal-Agustin, & Contreras, 2006). Two deficit levels of hourly loads were chosen for all system simulations for the present load, which were 5% and 15%. Shortages were not allowed since the Telecom load at the base station requires steady supply.

In addition, 10% of the capacity was reserved for sudden increases in demand or sudden decreases in the renewable power output. Higher reserves of 25% for solar PV and 50% for wind generation were set for the renewable output. These higher levels were required because of the inherent variation in the output of renewable energy sources.

The output of the simulation revealed a list that indicates the lowest system configuration cost among all the feasible technology combinations that were selected for consideration. According to the collected data, the wind speed available in Ho is 3.06m/s and for Jema is 2.81m/s. These wind speeds are insufficient for electricity generation. The solar intensity is higher in the northern sector and therefore, Jema has higher solar power generation capability. It is also evident that electric power can be produced by harnessing the wind energy in areas such as Ada-Foah which has high wind speed at a relatively cheaper cost (See 7.14.1). The NPC and COE of Ada-Foah are lower than the Ho area because, Ada-Foah is an area identified to have high wind speed ideal for electric power generation in Ghana. It is obvious from the simulation that solar resource potential can be harness to generate electricity all over the country. Table 7:29 below shows simulation comparison.

Site	System	Cooling System	Initial Cost ($)	Cost of Energy (COE, $)	Net Present Cost (NPC, $)	Operation Cost ($)	Fuel Con./yr. (Litres)
Kabakaba Hill (Operator 1 Vodafone – Ghana	PV/Wind/ DEG	*A/C*	76,450	0.566	228,103	11,731	5,613
Ada-Foah (Operator 1 Vodafone – Ghana)	PV/Wind/ DEG	A/C	76,450	0.37	149,196	5,626	1,576
Ada-Foah (Operator 1 Vodafone – Ghana)	PV/Wind	Free Air	45,453	0.319	77,881	2,537	No fuel
Ada-Foah (Operator 2 Airtel–Ghana)	PV/Wind/ DEG	A/C	76,450	0.398	237,078	4,690	1,009
Jema (Operator 1 Vodafone – Ghana)	PV/Wind/ DEG	A/C	76,450	0.58	233,807	12,172	5,776

Table 7. 11 Summary of lifetime costs comparison for selected BTS from simulation

Source: HOMER simulation

The HOMER software package proves to be an efficient and flexible tool for optimum sizing of hybrid power based on renewable source. The results shows the most feasible configuration for different areas. The simulation clearly shows that by harnessing the renewable energy resources, reliable electricity can be produced to power the loads at all BTS in Ghana.

This could lead to the end of electric power challenges to Telecom operators in Ghana and other countries in the sub-region.

Chapter 8 – Interview Results and Sustainable Energy Application in Telecom (SEAT) Framework Development

8.1 Introduction

The research focused primarily on a qualitative approach through the process of interviews and a partial quantitative approach with a case study and simulations. Because of the approach adopted for the study, it would have been more difficult to just conduct quantitative data collection, since there were only six mobile Telecom companies and the stakeholders for both Telecom and renewable energy production were few in Ghana. The study was restricted to energy consumption at three BTS sites at different locations in Ghana. Though there were limitations, the study identified some significant findings.

Data was collected using interviews based on questionnaires (see Appendix B-1 & B-2). The questions were prepared for only two categories. The first category was the mobile Telecom operators within Ghana. The second category was the communication, energy and environmental stakeholders. The interview questions were carefully selected for each category. The questions were selected with the motivation to gain an understanding of the role of energy and its adverse effects in Telecom and ICT operations as perceived by the stakeholders. The principal question considered throughout the research was whether any reliable power supply source could be provided for the Telecom/ICT industry in Ghana. This source should be an alternative to the non-renewable energy sources currently used in Ghana.

Interviews were conducted with representatives of the four Telecom companies and thirteen stakeholders (i.e. government regulatory agencies, private power companies, energy consultants as well as power distribution companies) and the four opinion leaders from the various communities. In all, twenty-one interviews were conducted.

Additionally, 60 survey questionnaires were distributed and garnered a total of 42 responses. The responses and interviews formed 70% of the outcome of our target (see Table 8.1).

Interview Respondents	No. Proposed	Actual Interviews	%
Telecom Companies	8	4	
Stakeholders	16	13	
Opinion leaders	6	4	
Total	30	21	70
Survey questionnaire Respondents	**No. Proposed**	**Actual Responses**	
	60	**42**	**70**

Table 8. 1 Interview and Questionnaire Respondent Results

A Sustainable Energy Application in Telecom (SEAT) framework was also developed. This framework seeks to suggest a sustainable electricity supply for Telecom development especially in developing African countries.

8.2 Success of the Study

The study can be classified as successful because the researcher is confident that the target groups understood all the interview questions and the questionnaire has been well distributed. The interview questions were open ended so this gave room for more elaboration on the topic. The duration of the interviews were minimal and perhaps even favorable, since the interviewees showed signs of enthusiasm. All elements of the questions were linked to the aims of the study. However, it was surprising to note several suggestive comments from some of the respondents regarding the line of questioning.

The use of the survey questionnaire was a supplementary way to explore what the population thought about the study subject. The questionnaire examined the respondents' knowledge about the various sources of energy used in the Telecom industry. The questionnaires were appropriate in that they were not too lengthy and did not cause the respondents to lose interest.

8.3 Research Findings

8.3.1 Questionnaire Responses

Out of the 60 survey questionnaires distributed in the three selected sites, 42 responses were received, forming a 70% response rate. The majority of the questionnaire respondents were between the ages of 25 and 35. In fact, 38.09% of the respondents were of this age class. The respondent quantity decreased as the average age of the sample group increased. There were 14 respondents between the ages of 36 and 45, eight between the ages of 46 and 55, and four between the ages 56 and 65 (Figure 8.1). The respondent age shows that the younger generations are more abreast with current issues of renewable energy than the older segments of the population in the country.

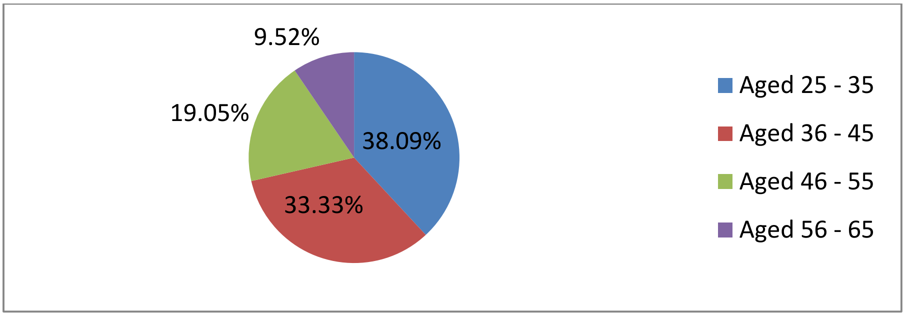

Figure 8. 1Age of Respondents.

Thirty-two respondents provided answers to questions relating to the type of power source used by the Telecom companies. This helped us in understanding that the expectations and views of the respondents are based on their knowledge and not on any prejudices. If we relate these questions to the earlier questions, the responses show that awareness of different sources of alternative energy continues to grow.

8.3.2 Interview Findings

A total of twenty-one interviews conducted, form 70% of the intended interviews (see table 8.1). The purposive sampling method was beneficial because the aim of the study was to explore the factors currently affecting Telecom and ICT development in Ghana. The purposive method of sampling meant that the interviewees and respondents were selected on the basis of their availability and knowledge of the topic. This method enabled us to elicit response that occurred in this study.

There were 17 interview questions that were prepared for the mobile Telecom operators. These questions were lumped into five groupings, while the 13 questions prepared for the stakeholders were lumped into four groups. The first questions in the interview were aimed at collecting background information. The second and third sets of questions for the Telecom operators were intended to provide answers to the technically related challenges that affect the electricity supply to the BTS in consideration of their network coverage areas. The fourth group of questions was directed towards solving problems regarding environmental sustainability.

The questions for the stakeholders were related to their contributions in the planning, regulation and promotional programs of the Telecom and energy industries in the country.

Table 8.2 and 8.3 shows the categorization of questions, the purpose and sum of responses for the Telecom operators and stakeholders, respectively.

Quest.	Objective	Purpose	Responses
1	Authority of respondents	To appreciate the authority level and influence of respondent in decision- making in the organization	Top and middle level engineer and planning officers
2-3	Network Mobile Coverage	To know the operational areas of the company and verify their coverage areas in the mist of the numerous challenges	None of the operators have full network coverage of the country
4-11	Electricity supply challenges	To establish the veracity or otherwise about the frequent power outages and how this outages affect the smooth operation of business.	The power supply is not reliable and is causing high operational cost.
12-14	Alternative power supply	To find out the preferred alternative power for uninterrupted operation of their businesses and the kind of incentive and privileges they stand to derive from regulators and stakeholders	The operators are ready to welcome alternative source of power supply, possibly from decentralized system
15-17	Environmental awareness and concern	To establish the level of environmental awareness of the negative effects of telecom operations especially the burning of diesel fuel for electricity production.	Though the operator are aware of environmental effects, their immediate concern is to maintain healthy telecom network

Table 8. 2 Summary of Interview Results for the Telecom Operators

Quest.	Objective	Purpose	Responses
1	Authority of respondents	To appreciate the authority level and influence of respondent in decision- making in the organization	Middle level management personnel, civil servants, and planning officers
2-5	Functions of organizations	To gain understanding of the roles being played by all stakeholders in electricity production and improvement in telecom service delivery in Ghana.	They are planners, policy/implementers and regulatory officers
6-9	Perception of Renewable Energy use	To establish barriers that prevents the fast development and adoption of renewable energy as alternative source of electricity supply.	They blame politicians for the monopoly of the energy sector and the challenges.
10-13	Framework to mitigate energy crises	To know if there are programmes and facilities in place in mitigating the energy crises of the country as well as promoting the development of ICT	There are many projects and programmes for power crises solutions and alternative supply of electricity, but the constraint is financial and some political maneuvering not to introduce any alternative.

Table 8. 3 Summary of Interview Results for the Stakeholders

From the responses to our interviews of the Telecom operators, as well as the stakeholders in both the electric power and Telecom industries, there were indications that electricity infrastructure and basic Telecom infrastructure are the key factors to the successful implementation of Telecom and ICT in Ghana. The Telecom operators and stakeholders all agreed that infrastructure is crucial for Telecom and ICT development. They all agreed that the lack of reliable electricity and Telecom infrastructure are contributing factors to the inability of the operators to have nationwide coverage. Additionally, frequent power outages also causes damages to their equipment, thereby increasing their operational expenditures. Researchers, such as Batcherlor (2003), Caspary & O'Connor (2003) and Mursu (2002) have determined poor infrastructure to be a major constraint to effective ICT development. Heeks (1999) also emphasize that the lack of appropriate infrastructure can affect the long-term viability of ICT. Caspary and O'Connor (2003) also observed the relevance of electricity in their Telecom development studies. Batcher.S, Norrish, Scott & Webb (2003) noted that any infrastructure that will enable a technology to operate is a key infrastructure, and in our case it refers to reliable supplies of electricity.

There was a general consensus among the Telecom operators, electricity providers, supervisory authorities and other stakeholders of both electric power and Telecom that education and knowledge of Policy and regulatory also have indirect effect on energy, Telecom and ICT development in Ghana.

8.4 Development of Sustainable Energy Applications in Telecom (SEAT)

8.4.1 Overview

This study has identified key areas of literature that are relevant to ICT development in Ghana and other developing countries. Following the review of literature, a conceptual research framework was developed. This framework is not new. For example, a well-known and cited example is the 'sustainability framework' which was developed by (Nicholas Ashford, 2011).

The modified framework to be implemented in the present study is the 'Sustainable Energy Application in Telecom' (SEAT), which represents an extension of 'sustainability framework' that includes developing countries, locally available resources and other factors that hypothesized to be necessary for ICT development (Figure 8.6). The framework itself is considered too broad for a single research project and therefore, there was a specific concentration on only ICT and renewable energy. SEAT provides guidance for testing and confirmation of feasibility and reliability of solar PV and wind energy use in the Ghanaian Telecom industry. Because of the nature of the research questions, the application of solar PV and wind energy in Telecom were explored.

Critical oversight of previous sustainable development research pertained to factors that hinder deployment of innovation in developing countries. It is thought that the identification of the challenges impeding the developmental activities of the Telecom and ICT industry in Ghana and other developing countries are critical. Also analyzing the benefits associated with the use of solar PV and wind energy at the mobile base transceiver stations is necessary. These two observations should be approached pragmatically by applying sustainable energy at the Telecom transceiver stations to improve the industry. Therefore, the purpose of the SEAT model is to demonstrate that the utilization of renewable energy technologies could be cost-effective and beneficial to the Telecom operators in Ghana and other developing countries.

8.4.2 Background of the SEAT Research Model

ICT and renewable energy are widely discussed phenomena among world leading politicians, policy makers and academicians (Roeth & Wokeck, 2011). ‘Sustainable’ in this context refers to the long-term development of Telecom and ICT that can improve information system delivery and to promote efficient use of resources. ICT and renewable energy can provide a wide variety of social and economic benefits, including rural development opportunities and the diversification of energy supply (Esty & Winston, 2006; Glenn & Gordon, 1998). Having classified ICT as an all-purpose technology that is required for data processing, using computers, computer software, mobile gadgets (e.g. mobile phones, tablets, smart witches etc.) to process, transmit and retrieve information, there is a need to provide reliable electricity supply for the easy application of technologies.

Currently, energy price spike and concern about energy security have ignited public interest and local effort to promote renewable energy (e.g. green energy) as a response to these contemporary challenges in general, and specifically for Telecom/ICT industry development. This is evident as U.S. President Barrack Obama declared renewable energy as a top agenda under his leadership in 2009. He followed through with a proposal of investment in renewable energy. This has made the study of renewable energy a topic of interest to many more researchers from a wide range of disciplines over the past decades (Weiss, 2013). In spite of various renewable energy studies and reviews conducted, there are still arguments on the inconsistent analysis of benefits related to renewable energy. Some researchers are of the opinion that, the findings have been mixed instead of focusing on a particular locality.

8.4.3 Sustainable Energy Application in Telecom (SEAT) Model

SEAT is a clear and independent conceptual model that is capable of delivering reliable, sustainable, cost effective and environmental friendly power to Telecom companies. It is entirely different from the traditional form of demand-side energy supply which tends to address only certain types of energy sources. At best, SEAT is the point-of-contact for reliable and self-generation in the same way that traditional power generations are the point of-contact for power supply. The most striking feature of SEAT is that energy users (Telecom/ICT) can be assured of reliable energy source which is abundantly and readily available and self-replenishing. The SEAT model draws comparison between the SEAT and other models of sustainable energy application concepts. The model is backed by some theoretical approaches from literature on energy and sustainable development that will reduce the conceptual gap of energy deficit in Telecom/ICT. The SEAT framework assumes that, electricity supply to the various mobile base stations currently is dependent on the ability of the power generation and distribution companies to provide reliable power that can meet the electricity demand at the various sites.

In order to appreciate the impact and importance of energy in sustainable development (United Nations, 1987), the study used 'system thinking' to understand the link between social, economic and environmental factors of sustainable development. According to (Haraldsson, 2000)**,** 'system thinking' can be regarded as the understanding of the connection and relationships between things that may be considered isolated. Leaning on 'system thinking', there is the need to explore and develop a solution to energy delivery challenges at the mobile cell site where grid power supply is either not available or reliable. The three factors identified 'The three pillars of sustainability', which are economic, social and environment (Figure 8.2).

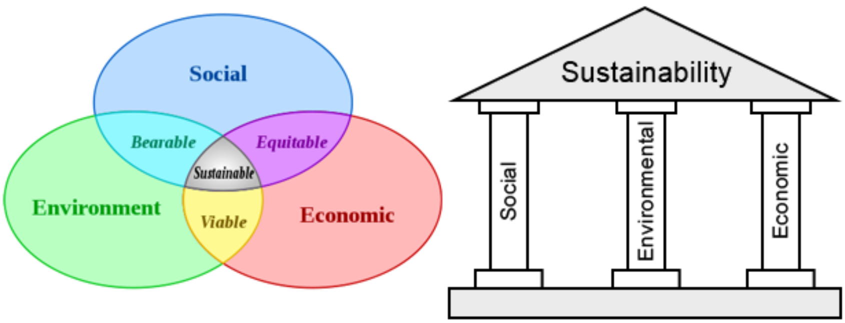

Figure 8. 2 Three Pillars of Sustainable Development.

Many countries focuses on solving a problem relating to one pillar at a time and because of the interest of members of the United Nations, these countries also focus their attention on the economic pillar of sustainability. Presently, organizations such as the United Nations Environmental Program (UNEP) and Environmental Protection Agencies (EPA) of many countries, have focused on the environmental pillar of sustainability in solving problems related to the environment. The World Trade Organization (WTO) and Organization for Economic Cooperation and Development

(OECD) usually directs their attention towards economic growth. OECD gives some attention to reduction in wars and justice which is seen as social sustainability. Some researchers have developed different models and frameworks based on the three pillars of sustainability. The Pillar Basic Model (Figure 8.3) is one of the popular models created which uses economics, the environment and society as the three dimensions for sustainable development. This model is based on societal development but does not clearly articulate all details of quality of human life.

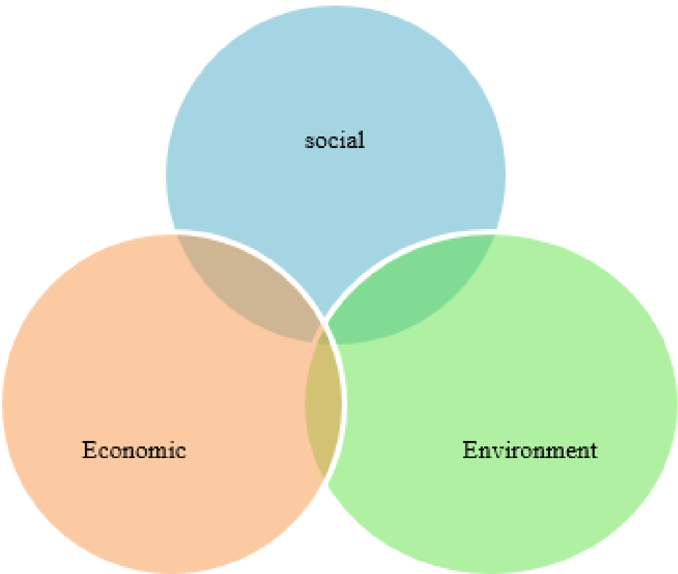

Figure 8. 3 The Pillar Basic Model.

The study also observed that 'The Egg of Sustainability' model (Figure 8.4) illustrates the relationship between people and the ecosystem. The model compares with an egg having a yolk within it (Moiseev & Prescott- Allen, 2001). Hence, social and economic development can only be beneficial if all the necessary resources are prudently managed. The egg of sustainability model considers the ecosystem to be a super coordinating system of economic development, social development and the environment.

Thus according to The Egg of Sustainability' model:

Sustainable development = human well-being + ecosystem well-being.

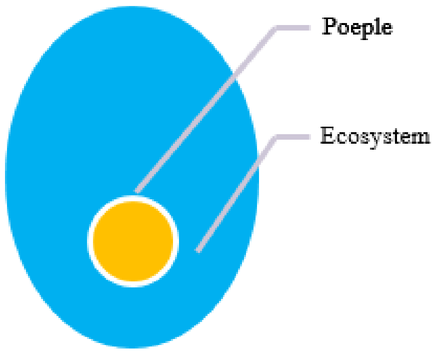

Figure 8. 4 The Egg of Sustainability Model (Source: IUCN)

(Ashford, 2011) also developed a framework that explores the concept of sustainable development by relating it to practical interpretations and this approach was adopted in this study. (Ashford, 2011)´s discussions of sustainable development were more general on examining the ways in which industrialized states are currently unsustainable and how economic and social welfare have influenced nature, health, safety and employment.

(Ashford, 2011) argued for the development of multipurpose solutions for the challenges confronting industrialized nations in terms of integrating economic, technological, environmental and industrial development (Ashford & Hall, 2011). However, his framework had little impact on sustainable development relating to social development in the context of developing countries.

Based on the ideas of ‘system thinking’, we believe that economic, social and environmental development are interconnected and it will be beneficial to develop a solution to electricity supply challenges at the mobile base stations where grid power supply is either not available or reliable in Ghana and other developing countries.

Other researchers suggest that many post adoption studies were conducted in order to teach lessons (Doss, 2006; Zhu, Dong, et. al., 2006). Prior research on IT application by Zhu, Kraemer et al., 2006) suggests that it is only when IT is integrated into the corporate value chain that it generates significant business value. As such, motivated by these issues, we define ICT application as a continuous variable (extent technology) that is being used to conduct value chain activities. The use of IT/IS technologies comprise of technologies that can be incorporated into the core functioning of administrative practices in order to transform the business processes of an organization.

Reviewing the technology application literature, a large quantity of studies were conducted on given technology adoption. As technology becomes more prevalent in everyday business functions, it is necessary to examine the factors that can contribute to the successful application. The conceptual framework is used to justify the purpose and antecedents to IT relevance and the postulated relationships.

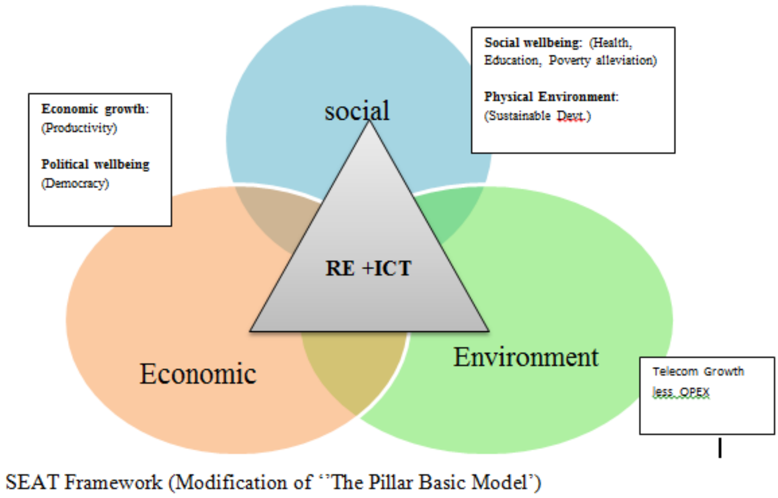

Figure 8. 5 SEAT Framework (Modification of ''the Pillar Basic Model'').

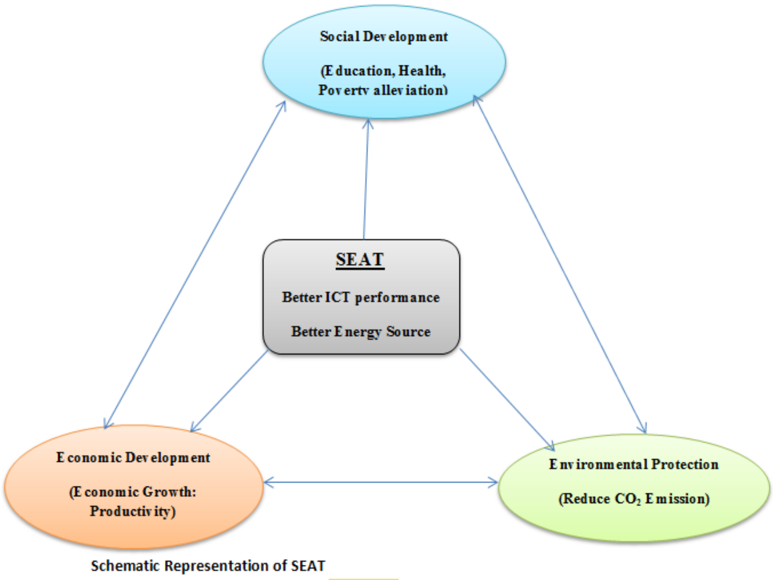

Figure 8. 6 SEAT Framework.

The first stage in the model considers the establishment of the factors that can affect Telecom and ICT development and sort them according to the three influencing factors: technology, organization and the environment. The second stage was simulation or test operation which arrived at a possible solution. If the simulation or test operation does not produce satisfactory results, it implies that the factors identified and causes needs to be reinvestigated. On the other hand, if there is a significant change after testing, then the proposed solution could be implemented to solve the problem (Figure 8.7).

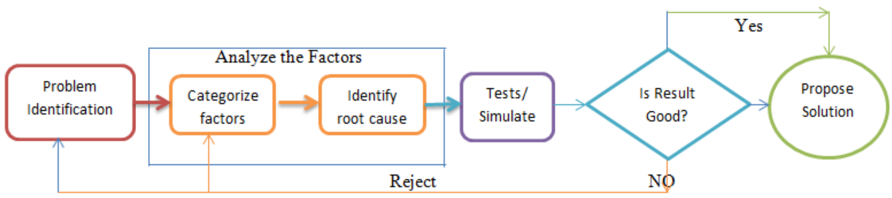

Figure 8. 7 Schematic Representation of SEAT.

The logic in the SEAT framework is that, if the existing energy sources (e.g. grid electricity and diesel engine generator) are unpredictable, have higher net present costs and have a negative effect on the environment through emissions, then these sources could not generate sustainable energy for the industry. On the other hand, if energy sources (e.g. Solar PV and wind) have less net present cost, no damage on the environment and are highly reliable, then the supply will be acceptable for sustainable development. Lower net costs and more reliable supply would stimulate social and economic activities and promote development. In the absence of reliable energy supply, the Telecom industry will not be able to function properly, therefore leading to less development.

8.4.4 Evaluation of Model

To evaluate the model, interviews and a questionnaire were designed and administered to different firms (i.e. Telecom operators, power generating and distribution companies, energy think tanks and stakeholders in both Telecom and energy sectors) in Ghana. Findings from some other previous studies were considered while some findings were deduced specifically for this study.

The constructs were sorted with regards to the technological, organizational, and environmental factors. Under technological considerations, perceived direct benefits, perceived indirect benefits and perceived barriers were factors examined and with the organizational factors, firm size and firm technology resources were considered.

8.4.4.1 Technology Context*:*

Perceived direct benefits considered seven items adapted from previous studies and publications. A five point Likert scale was used to evaluate the respondents/respondent's acceptance of answers in which 5 indicates strong agreement and 1 indicate strong disagreement.

Perceived indirect benefits also considered six items adapted from previous studies and publications. A five point Likert scale was used in evaluating the respondents endorsement of answers in which 5 indicates strong agreement and 1 strong disagreement. Perceived barriers were examined by counting the whole set of items. These items were adapted from surveys and journals (Chau and Tam, 1997).

8.4.4.2 Organizational Context:

Firm Size:

Total number of employees and total revenue have been used in determining firm sizes in past studies. However, for this study, firm size is determined by the number of employees of the Telecom operators of the various companies in Ghana. This study also examined the technical resources that are available to the Telecom companies. This was measured by the existing power supply from the grid, the use of diesel engine generators and the proposed renewable energy.

8.4.4.3 Environmental Context:

Telecom industry competitors and their relationships with regulatory authorities and customers were grounds for considering the way the organization engages with their customers. The stakeholders, together with customers and suppliers, are capable of coercing an organization into doing business on their terms.

8.5 Advantages of SEAT

The uniqueness of SEAT is the use of renewable energy and ICT to promote easy, reliable and cheaper communication. The use of renewable energy technology can lead to more efficient uses of resources therefore posing less stress on the environment and even cleaning the environment. Renewable energy will reduce the negative environmental effects, such as pollution and emissions, which are the end products of thermal and diesel power generators. Pollution and emissions, in general, cause poor health and so polluted environments may cause an increase in social services and less productive socio-economic activities. According to (Martinussen, 2004) “as a result of bad health conditions, the poor are generally less productive and continue to have little income and consequently, their purchasing power remains highly inadequate”.

The SEAT model could go beyond the conceptual level to the practical implementation of the effective energy scenario for the Telecom industry that creates or expands economic and social opportunities for a growing share of the population. The model may also help in fostering social and economic inclusion through participation of the public, private and civil society sectors through integrated efforts towards development of an inclusive knowledge society.

8.6 Conclusion

The model shows that the contribution of renewable energy when tied to ICT could cause significant economic and social changes in development. A direct socio-economic quality include the productive structure of ICT and the relationships between the stakeholders in the renewable energy project may play a relevant role in this regard. Renewable energy, such as solar PV and wind sources, are most suitable, particularly in the tropics where these sources are abundant. The SEAT framework stimulates a new avenue for discussions/dialogues and policy development that bring forward the role that innovation can play in economic growth and well-being in Ghana and other developing countries. The SEAT framework has shown the capability of providing an advantage of economic growth, social benefits and also minimizing the adverse effect on the natural environment which are the challenges of our time. Though SEAT might look more attractive and beneficial, there is still a strong need to find a more effective method of promoting Telecom development. The sole introduction of renewable energy is not sufficient enough for Telecom development. The changes in the social and institutional system, such as user practice and regulations, are inevitable. This is because SEAT needs to be featured in the Telecom authority and Ghana government policies.

Chapter 9. Discussions on Research Questions and Challenges

9.1 Introduction

The main policy required for implementing solar and wind energy for electricity generation in Ghana already exists. For example, it is the desire of the government owned electric power generating company (Volta River Authority) to produce 80% of national electricity from renewable sources (including hydropower). Also there is legislation on feed-in tariff obligation for connection of solar and wind energy to the national grid. However, the share of solar and wind energy in electricity generation is minimal because of a number of barriers that exist. In an attempt to find an alternative source of electricity supply that is cost effective and reliable for Telecom and ICT development in Ghana, HOMER software simulation was used to show the detail cost comparative elements of renewable energy for different power source configurations. It was clearly displayed that, for reliability and cost effectiveness the use of solar PV and wind energy in the BTS in Ghana is favourable for Telecom and ICT development. Here, the research aims, objectives and questions are examined through further data analysis.

In this chapter, analysis of the main barriers i.e. (a) policy, regulation and administrative and (b) economics are considered. Both barriers are considered equally important in limiting solar photovoltaic and wind energy application in Ghana.

In addition, a brief overview of environmental and technical constraints are also discussed. The analysis is based on documents reviews, interviews with Telecos in Ghana, energy and telecommunication stakeholders and experts.

In order to achieve the aims of the study, all research questions had to be addressed. This study had one key research question, in addition to several subsidiary questions. The main research question is, how can renewable energy application enhance Telecom/ICT operation in Ghana?

The subsidiary research questions were:

1. What are the critical factors influencing sustainable development of telecommunication and ICT use in Ghana?

2. How does the unreliable supply of electricity affect the operations of the mobile telecom operators?
3. How would a framework be modeled to incorporate the challenges hindering sustainable ICT application?
4. Can renewable energy provide reliable electricity for the base transceiver stations in Ghana?
5. What will be the financial benefit/cost of renewable energy to the Telecom operator(s)?

The response to the question “How can renewable energy application enhance Telecom/ICT operation in Ghana?’’ requires a great deal of effort. By answering all the subsidiary questions satisfactorily, renewable energy can then become an alternative power supply for the Telecom industry in Ghana.

The answers to the research question, “*what are the critical factors influencing sustainable development of telecommunication and ICT use in Ghana?’’* was composed of seven factors (Figure 9, 1).

During the analysis, the theory developed from a holistic perspective on the identified factors. Thus, the study acknowledge the link between the identified factors in the theory. Some of these factors are very clearly linked to the situation of the research interest as a developing country, while others are general.

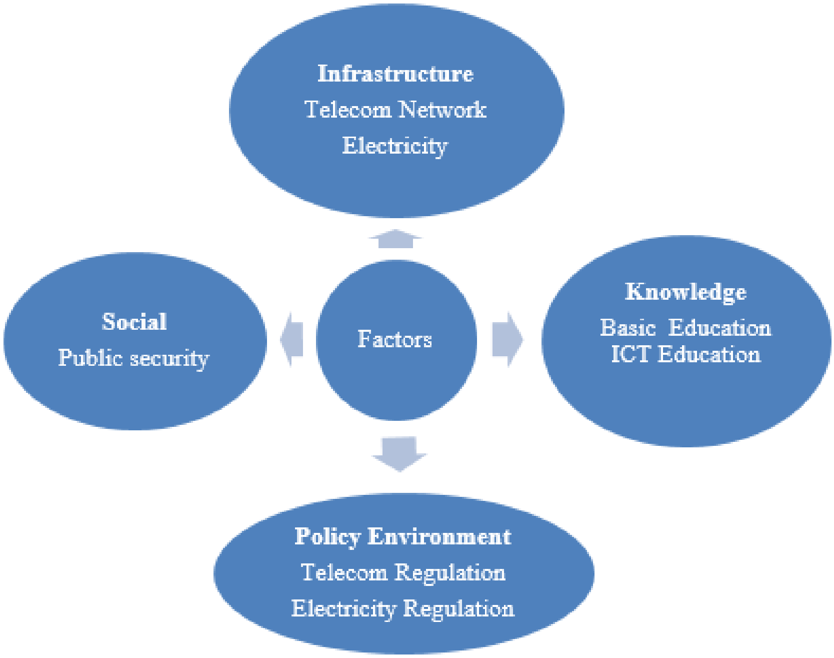

Figure 9. 1 Factors impeding ICT developments in Ghana.

The answer to the research question, "*how would a framework be modeled to incorporate the challenges hindering sustainable ICT application?''*.

A modified framework was implemented. The study initiated an investigation into the sustainable development framework by Nicholas Ashford. Ashford´s framework was modified by adding renewable energy (e.g. solar and wind) to establish the three pillars of sustainable development to facilitate an effective use of the framework in developing countries, especially Sub-Saharan Africa. The study observed that Ashford's framework was geared towards the industrialized nations and did not consider developing countries. Also, it was more about work and not for social development. Therefore, we suggested a modification which is the SEAT framework. The SEAT framework considers the modification of Ashford's framework to be beneficial because it now incorporates innovations that include developing countries and makes the sustainable development framework more usable for development by all countries (please see Figure 9,2).

In SEAT, we considered renewable energy to be the catalyst for sustainable ICT which should drive economic, social and environmental development. The study illustrate this by positioning the renewable energy close to ICT to signify its importance. Further, ICT is placed at the center of the three pillars as a cornerstone for sustainable development in Ghana and other developing countries in Sub-Saharan Africa. However, we are of the opinion that the model is still insufficient for sustainable development research of the entire ICT application since it only focuses on reliability of power supply for the ICT and Telecom industry. Therefore SEAT model needs to be complemented in order to make it universally acceptable.

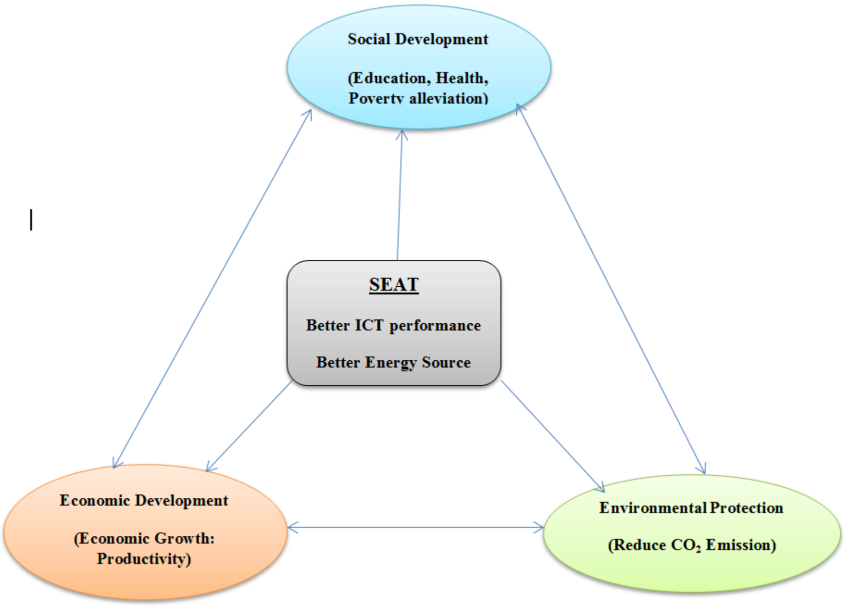

Figure 9. 2 The SEAT framework.

To address the fourth research question: "*Can renewable energy provide reliable electricity for the base transceiver stations in Ghana?''* the study examined the data on the trend of power generation and distribution in Ghana, thus in both urban and rural areas. As discussed in chapter 2, Ghana is endowed with abundant renewable energy resources and due to its location in the tropics, it has solar radiation ranging between 4kWh/m^2 and 6kWh/m^2 with a corresponding sunshine duration of 1800 hours to 3000 hours annually. However, there are some variations in terms of the diffusion levels across the country. The southern sector of the country has a high level of radiation diffusion while the northern sector and the coastal belt along central and greater Accra regions have low diffusion. Ghana also has more than 2,000MW of wind energy potential (Park, Richard, & Schafer, 2009). The coastal belt has an average wind speed of 6m/s. It is also estimated that the country has 2,420MW of hydroelectric resource potential (Ministry of Energy and Petroleum, 2012). These findings revealed the various energy resources in Ghana; however, they are only indications of viability because if we consider the hydroelectric generation potential of 2,420MW, only 1,183MW has been installed (GRIDCo. Ghana, 2010). With an increasing demand for electricity and through government efforts to connect the rural areas to the national grid, the electricity services are becoming poorer by the day to the extent that the average continuous power supply without outage and fluctuations in a day is four hours.

To address the research question: "*What will be the financial benefit/cost of renewable energy to the telecom operator"?* the study used the HOMER energy simulation software. This software helped determine the most appropriate renewable configuration that demonstrates the relevance of renewable energy in Telecom and ICT. From the simulations, it is obvious that, it is possible and technically feasible to integrate solar PV into the Telecom base transceiver stations in all parts of Ghana. The study shows that integration of wind power into the Telecom power system is feasible and technically possible along the coastal belt of the country where wind speed is quite high for electricity generation.

9.2 Implications of the Study

The study has several implications for both ICT and energy application research. We try to build on previous studies and provide valuable information regarding energy and ICT implementation in developing countries. This study adds to the empirical evidence and possibility of broadening the TOE framework to include local organizations and groups especially in developing countries context. From the SEAT model, it has been discovered that the application of renewable energy in ICT is not only dependent on technological factors but also on socio-economic benefits that are related to organizational and environmental factors.

The outcome of this study shows that Ghana possess abundant renewable energy sources that can serve as an alternative source of electric power supply. However, successful harnessing of the resources, particularly from solar PV and wind energy to the rural areas is precarious. The findings therefore have wide range of implications for general provision of modern form of electricity to the rural areas and for Telecom/ICT industry in Ghana.

9.2.1 Policy, Regulation and Administrative Implication of Findings

Long-term and clear policy framework is important in deciding the direction and investment in technologies. A general problem for solar photovoltaic and wind energy application in many developing countries including Ghana, is that electricity generating systems and policies were developed with the view of large-scale power generation. These systems and policies do not favour small-scale power generations such as solar photovoltaic and small wind turbines. There is also the lack of willingness to support the introduction of alternative electric power generation to the traditional form of electricity which leads to inconsistencies and gaps in the legal documents. In addition, a number of regulatory barriers are hampering the development and introduction of renewable energy especially solar photovoltaic and wind power. Some of the regulatory standards are difficult to be met by ordinary Ghanaians interested in using renewable energy on a small-scale. The study tries to analyze the main policy, regulatory and administrative barriers to renewable energy application in Ghana.

9.2.1.1 Conventional Centralized Electric Power Generating System and Low Priority for Alternative Electric Power Generation

Electric power generation in Ghana was planned in a centralized way by the Colonia masters (British) in the twentieth century. Electricity was generated from big diesel plants for use in the mining areas of Ghana and for domestic use by the British.

After independence in 1957, there were no major changes in the energy sector. Rather, a hydropower plant was constructed (Akosombo dam) to increase the power generating capacity for industrial development and extension of electric power to all big towns and city across the country. With growth in population and high industrial demands, thermal power plants (crude oil plant) were added to the existing diesel generators and hydropower plants. With the aspiration of being energy efficient country and meeting the power demands, solar photovoltaic power systems were introduced. For many years, renewable energy option apart from hydro was not considered seriously. There were statements such as “the storage of solar power in battery is dangerous, and wind energy is too noisy” (expert 2011). This was being indicated as the general opinion.

9.2.2. Lack of Strategic Approach and Policy Implementation

Until recently, there were no targets for the promotion of renewable energy although one of the functions at the ministry of energy was to propose targets and promote renewable energy applications. Indicative target for electricity generation from renewable source was adopted in June 2008. Action plans for implementing renewable energy are under development, but a 20% target for solar photovoltaic in the country´s electricity mix is anticipated by 2015. There is no program for the promotion of wind energy. The introduction of feed-in tariffs legislation has been very slow.

9.2.2.1 Inconsistency in Policy and Lack of Strategic Approach.

The lack of a strategic approach is also linked to inconsistency in the policy of renewable energy implementation. For example, a number of programmes on energy efficiency were adopted to improve electricity conditions in Ghana in recent years, but these programmes and initiatives were abolished after a few months.

Another inconsistency is the proposed annual feed-in tariff that is not included in the legal acts. Therefore, there is the possibility that the feed-in tariff which is considered sufficiently high enough to repay for investment cannot be guaranteed. Also, the limitation with feed-in tariff is that there is no limit for the amount of renewable energy that can be fed into the national grid in the proposed draft bill. This creates uncertainties and increases the investment risks.

9.2.2.2 Legal Provisions not suited for Small-Scale Electricity Generation

The existing legislature on electricity generation in Ghana is better suited for the needs of large-scale power generation. The implementation of the existing legislation on solar and wind energy are not fully considered. This is due to the low integration of solar photovoltaic and wind energy technologies in the Ghanaian system at the time of putting the legislation together and also because of the lack of knowledge of the possible implications of those technologies. In addition, the administrative procedures for implementing renewable energy are complicated for a small-scale solar photovoltaic power producers. Some of the requirements for accepting renewable energy are redundant and impossible for the investor(s) to produce. For example, in project proposal for wind mill, the investor(s) is required to provide at least ten years data on wind speed and other information for any particular location of a project. It is difficult and impossible to present such data for most wind projects if the project sites are not located close to Ghana Meteorological Service Department monitoring centres.

According to an article in the existing law, any investor in solar photovoltaic should provide a proof of adequate software for the photovoltaic system. There is no clarity on how one can prove that the software accompanying the solar photovoltaic is compatible with the Ghanaian grid network. This requirement is a setback on the level of knowledge on renewable energy. Under normal circumstances, software is not essential in running a photovoltaic system, instead the software is only used or needed to monitor the electricity generation and the software comes with the investor(s) and it is not site specific.

9.2.3 Inexistent Policies for Small-Scale Power Generation

There is no policy targeted at the installation of solar photovoltaic and wind power at private homes or public buildings. Without a strong investment supports, it is unlikely that small power generating technologies will be purchased since the income levels of the average Ghanaian is too low and also there is constraints on public sector budgets. Therefore, in order to increase public awareness of the potential benefits of solar photovoltaic power and increase its share in the country´s energy mix as well as develop the photovoltaic industry, there should be a policy on small-scale power generation in Ghana.

9.2.4 Lack of Inclusion of Solar Photovoltaic and wind power in Planning

Another serious limitation for the use of solar photovoltaic technological potential is that there is no zoning in the country showing the regions where solar and wind potentials are high for electricity generation and there are no record of potential negative environmental consequences in adopting either wind power or solar photovoltaic power systems.

9.3 Economic Limitations

Economic limitations of renewable energy comes from limited knowledge on system specification of the power units and over estimation of the components such as battery autonomy which usually escalates the cost of installation and operation of some renewable energy systems making them more expensive than the conventional power generators. But with advancement in technology and proper policy administration, the economic challenges can be overcome. This section of the study discusses the comparison of economic benefits of renewable energy and the conventional power generation.

Within the electric power generating sector, the regulator deliberately do not declare all the costs involved in energy generation. This leads to underpricing of electricity generated from technologies that have negative environmental and social impacts. For that matter, renewable energy technologies which offers better environmental, social and economic benefits are not valued appropriately to make them competitive. In Ghana, electricity generated from the conventional power sources are supported by the government, thereby reducing the actual cost of construction without considering the environmental impact in the total cost. Also there are insufficient initial investment support and no promotion for sustainable electricity generation.

9.3.1 Cost of Electricity Generation and Fuel Cost in Ghana

There is no detail information available on the cost of power generation and there is no study on the negative impacts of the conventional power generation. However, a representative of ministry of energy who was one of the interviewee indicated that the generation costs of power in Ghana ranges between 3.7 and 7 cents ($)/kWh.

The cost of power generation from the conventional sources in Ghana are low due to several reasons. First, the initial investment were supported by the state. Secondly, the environmental consequences of the construction and generation were not sufficiently included in the initial cost.

9.3.2 Challenges with Reward Schemes

The lack of preferential tariffs for the various electricity generation technologies is one of the main hindrances to investment in renewable energy. The suggestion of feed-in tariff in 2010 is the beginning of positive development. Since 2010, feed-in tariff for solar photovoltaic and wind power have been proposed to the parliament of Ghana. The proposed feed-in tariff will facilitate the development of projects where sunshine and wind speed conditions are favourable for electricity generation.

9.3.3 Limited Funding for Renewable Energy

As stated earlier (chapter 6.5.5), the limited funding for research and development (R&D) for renewable energy in Ghana also limits the uptake of renewable energy technologies in Ghana. The possible national source of funding are the Ghana Educational Trust Fund (GETFund) and Council for Scientific and Industrial Research (CSIR) and private donors. Unfortunately, renewable energy research is not a priority of these organizations as well as private donors so they provide limited or no support for research and developmental activities in the areas of renewable energy technologies.

9.4 Imperfect Competition

Imperfect competition is one of the challenges confronting the application of renewable energy such as solar photovoltaic in Ghana. Volta River Authority (VRA) and Electricity Corporation of Ghana, have enjoyed state monopoly over electricity generation and distribution in Ghana for many years. This situation have created a number of problems for grid connection and purchase of renewable energy. Many means can be employed by these organizations to prevent the connection of solar photovoltaic systems, including charging very high and non-transparent connection fees (Jorss et al, 2002). Until 2010, the decision on the condition for connecting solar photovoltaic to the grid in Ghana was the sole authority of VRA. Any attempt to connect solar photovoltaic to consumers will not be beneficial to the conventional power generating company (VRA) from economic point of view. It could cause additional expenses and losses as VRA will be required to bear the cost of connection. VRA will be required to purchase the electricity generated from the solar photovoltaic system at a tariff which the company may not like.

It worth noting that the prices of electricity are determined by the government of Ghana which tries to ensure that the electricity price do not increase significantly thereby causing VRA not to achieve full cost recovery for electricity generated from the conventional sources. As a result, VRA and others in authority tries to oppose or postpone the connection in many ways. They claim that power generated from private solar photovoltaic systems is not technically feasible to synchronise with the national system. Also, they argue that power from photovoltaic systems should be at least 5000kW otherwise there could be imbalance and losses in the distribution network due to the fact that the voltage will have to be transformed to a higher voltage. But with the changes in policy, all decisions, conditions and fees determinations will be under the control of the Public Utility Regulatory Commission of Ghana.

9.5 Inadequate Information

The problem of inadequate information can be classified into three groups, (i) lack of information (ii) high cost for information and (iii) low accuracy of information.

In Ghana, there is insufficient data on potential, investment process and availability of finance for renewable energy. It is not easy to obtain information on wind resources from authentic sources and it is extremely difficult to get access to reports on wind and solar photovoltaic potentials prepared under various studies. The reports gathered in this study were obtained through personal contacts and were supposed to be used only for this research.

Another problem with data on resource availability is that the data were collected for other purposes. For example, data on wind speed at 10m height which were part of regular meteorological observation may not always be ideal for wind power generation assessments. There is also limited, inadequate or outdated information on investment process. There is some information on investment in some district assemble websites, but other districts have no information.

Another problem with inadequate information is that renewable energy technologies are relatively new and there is no proper training for responsible officers at the relevant authorities. This can be great hindrance to investment in renewable energy in Ghana since it can cause delays in soliciting the relevant information and also requires additional resources for responsible institution. There is also insufficient knowledge and awareness of the negative impacts of the conventional electricity generation on the environment. This leads to lukewarm attitude by decision makers towards introduction of renewable energy.

9. 6 Technical Limitations

A detailed study of the technical limitations is not the primary objective of the present study. However, the increasing electricity crises in Ghana and issues related to grid connection has become important. Below is a brief discussion on technical challenges.

Since the Ghanaian electricity system is centrally planned, the injection of solar photovoltaic and wind power into the existing system could pose some technical challenges. For example, majority of Ghanaians reside in rural and remote parts of the country, so if power generated from the solar or wind system is connected to the grid, there could be problem with frequency control. It could also be difficult to predict the wind speed at all time which could affect technical planning. The injection of solar photovoltaic to the medium and low voltage grid could create reverse flow of current to the normal direction (which is from high to medium to low voltage) and that could impose a significant change to the standard regulating the design and operation of medium and low voltage electricity networks.

In order to maintain high level of security of electricity supply in Ghana, there is the need for extension and enforcement of grid interconnectivity planning. This planning should be concern with automation, relay protection and control. Also there should be investigation that aim at harmonising rules for smooth integration of renewable energy.

9.7 Environmental and Social Impact

One of the greatest benefits of renewable energy is that there is less or no environmental pollution and it has no harmful effect on human life when used in the generation of electricity.

Unlike the conventional form of electricity generation such as crude oil and natural gas which leads to the decrease of resource depletion, pollution and carbon emissions. It should be noted that hydropower generation which is counted among renewable energy has some environmental impact such as deforestation and destruction of the habitat. At present, a number of small hydropower potentials have been identified in Ghana. For instance, because of the proposed feed-in tariff which allow small hydropower generation from private owners, several proposals have been submitted to the ministry of energy for consideration.

Another area of concern is the wind mills along the coast of Ghana. The coastal belt of the country have wind speed that is ideal for electricity generation and the introduction of wind mills will possibly scare birds away. There is also negative position or views and protest from some groups notably Non-Governmental Organizations (NGOs) regarding the renewable energy particularly hydro and wind mills. Their stand is that there should be a transparent environmental impact assessment procedures.

At the moment, there are no serious protest from the local population against the introduction of renewable energy. However, the main constraints are the low awareness and interest of the general population in renewable energy technologies.

9. 8 Implications for Developing Countries

Understanding the factors that inspire the successful acceptance of technology in a country can support companies, private organizations and governments with their economic projections. The results of the study show that the realization of benefits that accrue from technology application can have a direct impact on the technology implementation. In the context of a developing country, there should be organized training to promote a firm's understanding of the numerous benefits associated with renewable energy and ICT technologies. Additionally, the finding revealed that perceived barriers can negatively affect the application/adoption decisions. Knowing that firms in developing countries have fewer resources, governments must recognize the limitations and develop programs that can help companies reduce those barriers. In our study, we did not investigate the national infrastructure because earlier studies linked application with adequate national infrastructure, such as quality Internet connections.

9.9 Theoretical Relation with Empirical Findings

Technology, Organization and Environment (TOE) framework has been fundamental in writing this thesis. The study indicates ways to adopt this theoretical framework in order to make it more applicable in the context such as this study in developing countries. Though the theory has been applied for analysis, development and diffusion processes within the information society (IS) (Zhu, Kraemer, & Xu, The Process of Information Assimilation by Firms in Different Countries: A Technology

Diffussion Perspectives on Business, 2006) (Zhu, Kraemer, & Xu, 2002), the theory has rarely been applied to technological development and application in developing countries.

Many individuals and groups have played diverse roles in this study which is considered important in understanding some of the drivers of renewable energy technology acceptance. These individuals and groups of people the study describes as intermediary bodies. From the study, the stakeholders within the energy sector and Telecom industry including politicians all have different influences on the acceptance of renewable energy. However, it is interesting to know that many people accept that renewable energy could be useful and worth implementing in the Ghanaian Telecom industry. On the other hand, some feel renewable energy technology is inferior and would prefer to continue coping with the existing challenges until the national grid performance improves. The study therefore suggest the involvement of local beneficiaries of the technology in TOE framework to examine the role of these local organizations in the acceptance of any innovation.

TOE framework can also be enhanced by examining the availability of natural resources and the influence of politicians. The introduction of this modifications will complement the environmentally focused approach that favoured TOE framework. It will also provide an improved understanding of the dynamics of technology development.

It is recommended here that studies should endeavor to use TOE framework for technological innovations in developing countries context in order to reform the framework of its acceptance since these elements are lacking in the present technology acceptance in developing countries.

9.10 Conclusion

The chapter analyzed the findings of the study by examining the responses to the questionnaires and interviews conducted with the various stakeholder groups in order to find solutions to the research questions. The study points out in this chapter that the government of Ghana has not provided any subsidies for individuals, organizations and companies willing to adopt to solar energy, as is the case in many developed countries. Even though on paper the Ghana government has proposed incentives such as tax reductions for both individuals and organizations ready to install solar power, the challenge of getting well-trained technicians for installations is vast.

The research shows that for solar PV to gain sufficient support, the government should provide subsidies and tax holidays to organizations and individuals, which would ensure price reductions. The solar companies have added high overhead charges to all solar equipment because there is no solar manufacturing or assembling company in Ghana. Every part of the product is imported and worst of all, the demand from the market is low. All these add up to the high initial costs that discourages people from using the solar PV system.

Chapter 10: Recommendations and Conclusion

10.1 Overview

The previous chapters analyzed renewable energy potentials and their integration into Ghanaian Telecommunication industry. The concluding chapter of the study commences with a short review of the research background by recapping the research problem in section 10.2 in order to ascertain that the objectives for the study have been achieved. The chapters also discussed policies that aim at facilitating the uptake of Renewable energy and their limitations and barriers. It describes the basic requirements necessary for promoting enabling environment, equal opportunities and possible impact of Renewable energy. Finally, the chapter considers suggestion for further research that is required.

10.2 Background

Ghana's electrification challenges has affected Telecom/ICT development over the years due to lack of long-term strategy and planning. To improve access to both modern form of electricity supply and Telecom services, the study set out to explore the application of renewable and sustainable energy in the Telecom/ICT industry in Ghana and other developing countries in order to ensure socio-economic development. Renewable energy should also serve as a solution to electric power challenges as well as an alternative and reliable source of electric power to the Telecom industry in Ghana. Under normal circumstances, electricity generated from renewable sources such as solar PV technology should be the most attractive for countries such as Ghana because the country has high solar insulation and dispersed nature of settlements. Unfortunately, the advocacy and education about the benefits associated with solar PV technology, especially in Telecom/ICT industry in the rural and remote areas has not yielded much result.

Given the importance and widespread application of IT/IS, the study enhances our understanding of technological application. The study revealed a combination of factors that underpin the general characteristics of solar PV application, particularly within the Telecom/ICT industry in Ghana. These findings contradict many other studies which stress that cost is the core factor in determining the application of solar PV. Also, the study identified that ICT is growing rapidly and the government of Ghana considers it as a tool that is required in achieving the developmental goals of the country.

Due to the highly dispersed nature of the Ghanaian settlements, about 59% of the population resides in the rural and remote areas of the country where it is not viable to extend grid electricity because of the high cost of conductors, transformers, switch gears and their accessories. Within the reach of the grid supply, the quality of power supply is poor because of outdated distribution system, low generating capacity of the power plant and high demand from the population (Ghana Grid Company, 2010). On average, customers have interrupted power supply and outages that last between six hours and four days. Telecom operators have depended on DEGs in order to be in business and maintain continuous communication without any interruption.

The use of DEGs has raised the operational expenditure because of the continuous running of the generator sets, regular maintenance of the engines and ever increasing fuel prices in the country. The highly dispersed locations and poor road network to BTSs also contributes to the high running cost of the Telecom companies as well as the cost of communication. In addition, the burning of diesel fuel produces CO_2 emission.

Fortunately, the country has abundant energy resources including solar PV and wind that has not been harnessed. Ghana has average solar irradiation that ranges between $4kWh/m^2$ and $6kWh/m^2$ daily with a corresponding 1800 to 3000 hours of annual sun shine.

Considering the energy challenges that have engulfed the country as discussed in earlier chapters, it is necessary to integrate electricity generated from renewable sources particularly into the Telecom industry in order to improve the performance of Telecom and promote the effective use of ICT which will enable energy security as well as help the country to narrow the digital divide.

Though solar radiation diffusion varies, the levels are sufficiently high in all parts of the country for electricity generation and this makes it justifiable to incorporate solar PV in the system for the purpose of energy security. From the data gathered, it is obvious that sunshine duration throughout the year is sufficient for electric power generation. The intension of introducing solar and wind energy into the Telecom system is to ensure a reliable power at all times to the equipment.

The introduction and acceptance of solar PV and wind energy could be considered as the initial stage of transition from unstable, conventional, thermal and diesel generation systems to a sustainable electrical power supply. If the rising cost of crude oil is considered in deciding the source of energy for power generation for the Telecom installations (BTS), it is clear that the use of renewable energy will not only be financially beneficial but also it will provide safe and reliable power for the industry.

10.3 Benefit and Potential of Renewable Energy in Ghana Telecom Industry

Renewable energy can be beneficial not only to the Ghana Telecom industry, but to the entire Ghanaian economy, society and the environment in many ways. Electricity generation from renewable energy sources can be an alternative source of electricity to the poor quality of electricity generated from crude oil power plants. Also in this way we could decrease the harmful emissions of the crude oil power plants. Development of solar PV system which has great potential in Ghana can promote decentralized power generation, support rural development and provide employment for the rural population.

Renewable energy can also enhance the grid. Electricity from renewable energy sources can be fed into medium and low voltage networks of the grid which is currently having severe problems with power quality (with voltage less than 150V instead of the required 220V+10%). As stated earlier, about 59 percent of the Ghanaian population reside in rural and remote part of the country, therefore solar PV can provide reliable off-grid electricity. When renewable energy´ share of electricity increases, there can be a decrease in crude oil import for thermal power plants which at present is very high. In chapter 3 (chapter 3.5.3), it was shown that there is a significant potential for renewable energy sources in Ghana, example; solar and wind. Nevertheless, it is obvious that the country is not harnessing the energy resource potential.

10.4 Policy and Regulating Recommendations

In the past years there were considerable advancements in renewable energy policies in Ghana but there are still many policy and regulating barriers (see chapter 6) that need to be resolved. To increase renewable energy share considerably in Ghana, ambitious but achievable targets combined with commitment should be adopted by the Ghanaian government and special emphasis should be placed on eliminating administrative barriers as they were identified as one of the limitations by the interviews.

10.4.1 Clear Policy and Legal Framework

In order to stimulate investment in renewable energy, there is a need for a strategic approach that will incorporate a clear framework and government commitment. The existing supporting mechanics for renewable energy technologies should be strengthened and new mechanics such as financial support for small scale and individual renewable energy producers be proposed. It is important to set ambitions but achievable targets for renewable electricity generation in Ghana and once targets are adopted and measures are enforced, great progress will be achieved. Although there is a basic legal requirement for renewable energy in Ghana, changes in acts are needed. There is the need to introduce obligatory connection to the grid, preferential tariffs for electricity generated from renewable sources such as solar and compulsory purchase of electricity from renewable energy.

The limitations to renewable energy in Ghana were discussed in chapter 6. There are a number of inconsistences or unclear provisions in the existing legislation that permits VRA and GRIDCO to prevent grid connection. Therefore, clear rules, clear procedures and penalty for non-compliance should be developed and implemented. Small scale power generators that uses solar and wind should be given the chance to connect to the grid and the cost of connection should be borne by VRA and GRIDCO. It is recommended that there should be a wide consultation with stakeholders such as the ministry of energy, the ministry of environment, the energy commission of Ghana, investors, VRA, ECG and NGOs in preparing new renewable energy law. Any opinion expressed by these stakeholders should be well considered and if there is a significant differences between the various stakeholders they should be reconciled to encourage a win-win situation to avoid possible problems or conflicts.

10.4.2 Measures to Decrease Administrative Challenges

Presently, administrative procedures relating to renewable energy in Ghana is cumbersome and time consuming. These procedures strongly discourages people interested in renewable energy projects and therefore streamlining procedures are necessary to achieve significant improvement at a minimum cost to the government of Ghana. Some of the measures can include the creation of a single agency for promotion of renewable energy. This agency will be responsible for providing information, advice on the various renewable energy potentials especially solar PV and wind energy, monitoring administrative procedures and support the preparation of documentations necessary for renewable energy projects. These measures will undoubtedly ease the administrative burden and provide enabling condition for greater use of electricity generated from renewable sources.

10.4.3 Policy Planning

Currently, renewable energy is not part of local or regional planning activities. It is essential that local and regional planning authorities include renewable energy in their planning activities because this could create local employments and improve reliability of electricity and protection of the environment. Local and regional authorities should designate areas for renewable energy projects. For example, creating maps of areas appropriate for solar photovoltaic system development, identifying areas with high wind speed for deployment of wind turbines and also set up targets for both the local and regional authorities for renewable energy share of electricity.

10.4.4 Policy for Promoting Small- Scale Electricity

The promotion of electricity generation by private companies and at household level has not been the priority of the Ghana government and there are no policy measure for it. The reason why private companies and individual households are not interested in generating their own electricity is that they see electricity supply as the sole obligation of VRA and ECG and also there is no co-financing of installations and lack of public funds. There is also low awareness about the advantages of renewable energy technologies and excessive constraints on company budgets.

In order to increase renewable energy share of electricity in Ghana, the government should provide some support in a form of loans or grants to consumers or set up requirements that will enable favorable installation of electricity from renewable energy sources into buildings. There should be an obligation for the share of renewable energy as being practice in Merton in United Kingdom. Merton Borough in United Kingdom has been implementing the obligation scheme in new buildings since 2003.

10.5 Recommendation for Financial Support

It was revealed in chapter 6 that economic limitations are some of the factors that impede renewable energy application. Therefore as consistent and legal policy frameworks are being established, it is essential to have financial support scheme that can complement and stimulate renewable energy technologies. This scheme can be in a form of financial support on renewable energy projects or preferential tariff for electricity. It can also be financial support of the initial investment.

10.5.1 Stable Renewable Energy Electricity Reward Scheme

Feed – in tariff has been the main financial mechanism for renewable energy in many European countries. Ghana has been considering the introduction of similar mechanism. Currently there are no preferential tariffs for wind and solar electricity generation. The problem has been the approach to be adopted or setting how much the tariff will be for a period of time.

The support for renewable energy should provide sufficient support for technologies at early stages of development. According to the conclusion of the third Forum of the

European Network on Energy Research (Haas at. el. 2004) which was based on the experience from Seventeen European countries, there is no single “best’’ support mechanism for renewable energy, rather commitment from governments, excellent design and continuous monitoring of application processes.

For a successful feed-in tariff few components are required. First, it is essential that tariffs are differentiated based on the actual electricity generated cost in order to provide opportunity for different technologies. Second, the tariff should be set up over fixed period to encourage investors. Setting up of an obligation on supplier or commercial consumers to increase their proportion of electricity from renewable energy sources can be another form of support. For example, United Kingdom, Sweden, Italy and some part of Belgium have this type of support scheme (EC, 2003).

10.6 Support for Initial Investment

The initial investment cost are some of the limitations to renewable energy (solar PV and wind) in Ghana. As discussed earlier in chapter 6, experts report indicates that it is very difficult to pre-finance solar PV on a large scale due to challenges in obtaining credits from financial institutions. This condition limits the uptake of small scale solar PV and wind energy technologies. It is necessary for the initial investment to be provided. It is therefore necessary that some form of initial investment support is provided that ensure banks to price the risks associated with solar PV and wind projects in order to stimulate the development of solar PV industry.

10.7 Tax Relief Scheme

Another approach for stimulation of renewable energy investment is to take off tax on renewable energy technologies import. In Ghana tax relief is given to large scale investors. A law can be introduced on import taxes on energy technologies. Adoption of some tax incentive for small-scale electricity generation in Ghana might be helpful. Another important aspect of tax relief scheme is that the government of Ghana should create an equal and useful play field for all electricity generation technologies. The exit practice only supports large scale electricity generation.

Countries such as Netherlands have tax relief schemes of about 44% on renewable energy technologies while Ireland gives 50% tax relief. These are some good examples that should be emulated by Ghana.

10.8 Research and Development Support

Support for research and development of new and emerging technologies such as solar PV and wind power in Ghana is essential since these technologies are not yet at a stage that they can compete with well-developed technologies but have the potential of becoming highly competitive in the near future. Unfortunately solar photovoltaic and wind power generation are not supported by the Ghana government. Unlike majority of European countries that provide significant research and development support for renewable energy studies, Ghana is lacking in this initiative. For example, United Kingdom has low carbon innovation programme (LCIP) support which aims to accelerate the development of new and emerging energy efficient and low carbon technologies and sustainable power generation and supply (SUPERGEN).

To initiate research and development practice in Ghana, the government should consider creating a national innovation fund and allocate some budget for developmental activities. Furthermore research capacity of individual and institutions on renewable energy should be enhanced by creating a network of experts that can collaborate on solar PV and wind power issues through funding of researchers within institutions and universities in the country.

10.9 Information Management

There is not enough information about the potentials of renewable energy in Ghana and the benefits associated are not recognized. To address the lack of information the government of Ghana can initiate massive studies on the potential of solar photovoltaic power system in all the regions of the country to map out in detail the potential location of resources. Since the initial investment cost for solar PV is somehow high, the Ghana government should support the banking sector with expertise on how to evaluate the risks involved in solar PV and wind power systems. Implementation of information management can be entrusted to private consultant(s).

10.10 Measures to Tackle Technical Limitation

The study revealed little information on technical limitations because that was not the aim of this research. However, several policy measures can be proposed based on the information gathered during the interviews with stakeholders. There is a need for developing clear rules and standards for connecting all forms of power generation to the national grid. Legal base that is relevant for connecting power from all power sources especially renewable energy sources should be clarified and all the opportunities that are being used presently to prevent or deny grid connection should be removed. Procedure and standards for grid connection can be developed by the utility regulator(s) in collaboration with VRA, GRIDCO and ECG.

10.11 Further work

The rapid development of Telecom and ICT depends largely on reliable electricity supply. However, considering the energy mix of Ghana, it is important to understand the role of energy in national development and its relevance in the telecommunication and ICT industry. Therefore, future studies should try to use the SEAT model in different analyses as well as incorporate the model into other research activities. Further research into the application of renewable energy should be considered in other sectors of Telecom and ICT with different load characteristics. This will help validate the full scale implementation of renewable energy for the entire Telecom and ICT facilities.

The following are recommended for future research:

- Extension of energy requires assessment studies within the Telecom sector. The result of such studies should unearth what Telecom operators and other potential users of solar PV and wind energy require technically.

- More studies on how to incorporate energy policies with development programs to provide a cross-sectional implementation.

- Regulatory framework studies should be undertaken to incorporate private companies in the electricity generation that uses renewable sources to serve the Telecom and ICT industry.

- More studies involving comparisons of different renewable energy sources. Such studies could also boost the understanding of benefits of renewable energies.

The ICT and renewable energy potentials in Ghana are unlimited, therefore the advocacy for their applications to promote sustainable development is required. From the outcome of this study, it was revealed that the unlimited and physical resource availability is not the panacea for successful solar PV and wind power dissemination within the Telecom and ICT industry, instead, their application is for gainful utilization to improve ICT for socio-economic development and advancement of Ghana. Telecom operators in Ghana should be encouraged to use renewable energy for their base stations.

10.12 Conclusion

Electricity generation for renewable energy sources such as solar PV and wind close to consumers or even by consumers like telecom operators can help accelerate sustainable development of Ghana by contributing to social, environmental and economic developments. Electricity from solar PV can be beneficial for Ghana by stimulating economic growth, local development, job creation, leading to decreased impact on environmental protection and energy independence. Solar PV and wind power can be a viable alternative for Ghana, but the energy resources has not been harnessed so far. The main focus of this research has been to contribute to the promotion of sustainable and reliable energy generation for the telecommunication industry in Ghana and also to provide a basis for further research on alternative sources of power supply to the telecom facilities which can minimize/eliminate the existing frequent electric power outages.

In order to do this, a detailed study of electricity generation potential, policy and telecom development in Ghana has been carried out. The study identified and analyzed the main barriers. The policy and economic constraint were studied and HOMER simulation was used to verify the technical and economic viability of electricity generation from solar PV system and wind power systems in Ghana.

The research has been based on extensive literature review, interviews with a number of experts, investors, telecom operators and other stakeholders. Questionnaires were also distributed to the grass root in selected study areas. The research has proven that there is a significant and unexploited energy potential. The potential for solar PV and wind power is significant and there is a number of opportunities for small-scale hydropower units. There are no definite policies and regulatory frameworks for adoption of solar PV and wind power systems and no support mechanisms for investors or for people interested in solar PV and wind power generations. It is obvious that Ghana government's priority is on large scale power generation from thermal power plants that uses crude oil. There are also lack of policy instruments, inconsistences in policies and lack of support mechanisms. These prevent the wider application of renewable energy, creates insecurity in investment in renewable energy and gives incentives to large-scale electricity generation investment rather than renewable energy. The existing instruments do not support renewable energy connection to the national grid. The lack of financial support for solar PV and wind power systems adversely impact on their wider application. This can be attributed to insufficient action on the part of the Ghana government.

Another significant limitation is also the lack of qualified experts in the public administration and engineers who understand the specifics of these technologies and technicians to carry out maintenance.

The study has proposed a technically feasible and environmentally friendly power generation system that is sustainable for the Telecom/ICT industry in Ghana. To achieve a reliable and cost effective electrification, the idea of sustainable energy application in Telecom model (SEAT) was suggested. The study focused on BTSs as serving the Telecom needs of Ghanaians therefore providing reliable electricity at the BTS will significantly reduce electricity bill and operational cost of the Telecom operator(s) while improving Telecom/ICT services.

The research concludes with HOMER simulations which reveals the technical and economic viability of solar PV and wind power system. Through simulations the appropriate configurations required from the renewable sources are identified.

A variety of design parameters, such as solar PV size, wind turbine size and battery autonomy have been considered in the design simulation. The minimum renewable energy required to supply the load were used for simulation with diesel generators to determine the best optimal supply. The optimization and sensitivity analysis of a solar PV/wind/DEG hybrid at the BTS indicates that the most feasible systems consists of 10 kW solar PV, 10 kW diesel generator, 10kW wind turbine and 36 pieced Trojan battery bank (360AH) for each of the study sites. (Please refer to Table 10.1)

BTS sites	Kabakaba Hill	Ada-Foah (1st operator)	Ada-Foah (1st operator)	Ada-Foah (2nd operator)	Jema
System	PV/Wind /DEG	PV/Wind /DEG	PV/Wind	PV/Wind/ DEG	PV/Wind/ DEG
Cooling System	***A/C***	***A/C***	Free Air	***A/C***	***A/C***
Initial Cost ($)	76,450	76,450	45,453	76,450	76,450
Cost of Energy (COE, $)	0.566	0.37	0.319	0.398	0.58
Net Present Cost (NPC, $)	228,103	149,196	77,881	237,078	233,807
Operation Cost ($)	11,731	5,626	2,537	4,690	12,172
Fuel Con./yr. (Litres)	5,613	1,576	No fuel	1,009	5,776
CO_2 Emission (kg/yr)	15,239	4,170		4,170	15,209

Table 10. 1 Summary of Characteristic of Selected Configurations at the Three Study Sites.

The simulation approach adopted in this study was meant to help determine the renewable energy configuration that can be replicated for all Telecom BTSs, especially in Ghana and other Sub-Saharan African countries because there is free and abundant sunshine through the year.

The combined data collection and analysis with the Hybrid Optimization Model for Electric Renewables (HOMER) simulation provided different power source configurations. This explained how and why mobile telecom operators' perception of renewable energy application in telecom should be preferred over the use of energy from diesel engine generators.

Our collaborative activities with the stakeholders in unearthing the challenges pertaining to energy use in the telecom industry were beneficial both economically and socially. It paved the way for easy access to information and facilitated our data collection at all levels of our study. The list of email addresses, several honest responses to our interviews and the various informal conversations all demonstrate the intimacy that was established as a result of our collaboration. The data and knowledge acquired can be used to improve our understanding of renewable energy as applied in the telecom/ICT industries in Ghana as well as other developing countries.

LITERATURE LIST

By providing a literature review this thesis investigates the factors that are hampering ICT and energy development in Ghana. It also investigates the potentials of renewable energy, their technical and economic feasibility to generate electricity. The purpose is to gain insight about the present electricity availability challenges within the Ghanaian Telecom industry and propose a possible solution that can enhance rapid development of ICT in Ghana and other developing countries.

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APPENDICES

Appendix A: Secondary Data Gathered

Appendix A- 1: Telecom network coverage areas of Ghana

MTN

VODAFONE

Tigo *Airtel*

Source. *www.Sensorly.com/map/2G-3G/GH/Ghana*

Glo

Source. www.Sensorly.com/map/2G-3G/GH/Ghana

Appendix A- 2: Energy Development

Number of people without access to electricity and electrification rates by region in the (million)

	2009				2015		2030	
	Rural	Urban	Total	%	Total	%	Total	%
Africa	466	121	587	42	636	45	654	57
Sub-Saharan Africa	465	120	585	31	635	35	652	50
Developing Asia	716	82	799	78	725	81	545	88
China	8	0	8	99	5	100	0	100
India	380	23	404	66	389	70	293	80
Other Asia	328	59	387	65	331	72	252	82
Latin America	27	4	31	93	25	95	10	98
Total (Developing Countries)	1229	210	1438	73	1404	75	1213	81
Middle East & others	1232	210	1441		1406		1213	

Source OECD/IEA Energy Outlook 2010

Power Plants	Owner/Operator	Installed Capacities (MW)	Maximum Capacity (MW)	% of Existing Capacity
Akosombo Hydroelectric Plant	Volta River Authority	1,023	1,020	52.7 %
Kpong Hydroelectric Plant	Volta River Authority	160	152	7.9 %
Takoradi Thermal Power Plant- T1 (TAPCO)	Volta River Authority	364	330	17 %
Takoradi Thermal Power Plant- T2 (TICO)	Volta River Authority	241	220	11.4 %
Takoradi Thermal Power Plant- T1 (TT1PP)	Volta River Authority	113	113	5.8 %
Mines Reserve Plant	Volta River Authority	80	50	2.6 %
Tema Thermal Power Plant- T2 (TT2PP)	Volta River Authority	50	50	2.6 %

Source: GRIDCo, 2010

Appendix A- 3: Solar Data from Ghana

10- Year Monthly Average of Solar Irradiation (kWh/m2/day) in 7 Synoptic Stations in the Northern sector of Ghana

Mon./ Town.	1	2	3	4	5	6	7
JAN	5.391	5.124	5.156	5.422	5.107	5.464	5.193
FEB	5.400	5.479	5.462	5.821	5.414	5.089	5.495
MAR	5.783	5.613	5.558	5.762	5.679	5.798	5.483
APR	5.958	5.890	5.862	5.797	5.968	5.859	5.711
MAY	5.934	5.869	5.919	5.710	5.859	5.873	5.507
JUN	5.719	5.510	5.415	5.091	5.188	5.611	4.972
JUL	5.339	4.954	5.044	4.645	4.684	5.135	4.356
AUG	5.098	4.841	4.629	4.494	4.531	4.937	4.120
SEP	5.324	5.004	4.957	4.827	4.771	5.125	4.405
OCT	5.677	5.472	5.623	5.540	5.347	5.641	4.927
NOV	5.616	5.695	5.674	5.520	5.650	5.649	5.127
DEC	4.824	5.213	5.165	5.251	5.121	5.074	4.905
AVE.	5.505	5.389	5.372	5.323	5.277	5.122	5.017

(Towns:1 =Navrongo, 2 = Tamale, 3 = Yendi, 4 = Bole, 5 =Kete-Krachi, 6 = Wa, 7 = Wenchi)

Adopted from Dept. of Mechanical Engineering, KNUST

10- Year Monthly Average of Solar Irradiation (kWh/m2/day) in 5 Synoptic Stations along the Forest Zone of Ghana

Mon./ Town.	KUMAS I	BEKWAI	ABETIFI	K´DUA	AKIM ODA	HO
JAN	4.818	4.695	5.032	4.711	4.505	4.872
FEB	5.313	5.084	5.525	5.139	4.771	5.224
MAR	5.305	5.265	5.558	5.260	4.884	5.509
APR	5.356	5.495	5.580	5.434	5.176	5.716
MAY	4.709	5.311	5.406	5.287	4.896	5.576
JUN	4.029	4.559	4.824	4.641	4.303	4.916
JUL	4.036	4.114	4.752	4.074	4.015	4.601
AUG	3.783	3.753	4.602	3.842	3.802	4.187
SEP	3.992	4.069	4.682	4.437	4.240	4.663
OCT	4.707	4.954	5.243	5.174	4.783	5.500
NOV	5.000	5.007	5.559	5.241	4.931	5.624
DEC	4.552	4.446	5.072	4.857	4.501	5.074
AVERA GE	4.633	4.729	5.153	4.841	4.567	5.122

Adopted from Dept. of Mechanical Engineering, KNUST

10- Year Monthly Average of Solar Irradiation (kWh/m2/day) in 5 Synoptic Stations Along the Coast of Ghana

Mon./ Town.	ACCRA	AXIM	ADA	TAKO RADI	SALT PONG	AKUSE
JAN	4.660	4.882	4.995	4.790	4.899	4.634
FEB	5.206	5.399	5.381	5.376	5.555	5.056
MAR	5.256	5.569	5.649	5.463	5.486	5.247
APR	5.665	5.605	5.937	5.663	5.684	4.951
MAY	5.416	5.051	5.570	5.227	5.354	5.281
JUN	4.613	3.936	4.978	4.361	4.440	4.591
JUL	4.189	4.242	5.064	4.384	4.670	4.304
AUG	4.527	4.230	5.065	4.227	4.482	4.108
SEP	5.107	4.382	5.510	4.589	4.997	4.727
OCT	5.623	5.178	5.872	5.518	5.678	5.297
NOV	5.510	5.466	5.480	5.553	5.692	4.766
DEC	4.930	4.986	5.359	4.975	5.153	4.810
AVER AGE	5.059	4.911	5.409	5.011	5.174	4.814

Adopted from Dept. of Mechanical Engineering, KNUST

Appendix A- 4: Wind Data from Ghana

Table D-2. Hourly Monthly Mean Wind Speed (m/s) for Aplaku at 12m (January 2001 to July 2002)

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Monthly Mean
Jan.-01	4.1	3.9	4.0	4.0	4.1	4.3	4.5	4.5	4.4	4.1	3.7	4.1	5.0	5.9	6.7	7.0	7.0	6.7	6.3	6.0	5.6	5.0	4.6	4.2	**5.0**
Feb	3.7	3.9	3.9	4.2	4.2	4.4	4.5	4.4	4.3	4.2	4.4	5.2	6.0	6.7	7.2	7.5	7.3	6.9	6.4	5.7	5.1	4.7	4.5	4.1	**5.1**
March	4.9	4.9	4.7	4.8	4.9	4.7	4.5	4.3	4.3	5.1	6.1	7.0	7.5	7.7	7.8	7.7	7.4	6.8	6.2	5.8	5.5	5.3	4.9	4.8	**5.7**
Apr	6.5	6.3	6.0	5.8	5.5	5.1	4.9	4.9	4.9	5.2	5.5	5.4	5.5	5.8	6.1	6.1	6.0	5.9	5.8	6.5	6.8	7.0	7.1	7.0	**5.9**
May	4.1	4.3	4.4	4.4	4.7	4.5	4.6	4.3	4.2	3.7	3.5	4.4	5.0	5.9	6.4	6.5	6.3	5.5	5.3	5.0	4.7	4.2	4.3	4.0	**4.8**
June	4.1	4.1	4.2	4.3	4.6	4.5	4.4	4.1	4.1	4.4	4.6	4.9	5.6	6.2	6.7	6.7	6.5	6.0	5.6	5.3	5.1	4.9	4.5	4.4	**5.0**
July	5.0	4.9	5.2	5.0	4.7	4.5	4.6	4.4	4.9	5.6	6.2	6.6	6.9	7.2	7.3	7.3	7.1	6.6	6.2	5.9	6.0	5.8	5.5	5.2	**5.8**
Aug	5.8	5.4	5.5	5.4	5.1	4.8	4.5	4.6	5.1	5.7	6.2	6.5	7.0	7.3	7.4	7.5	7.4	7.1	6.7	6.4	6.4	6.2	6.0	6.0	**6.1**
Sept	5.3	5.2	4.7	4.8	4.8	4.6	4.4	4.6	4.8	5.3	5.9	6.7	7.4	7.7	8.2	8.2	8.1	7.9	7.2	6.8	6.2	5.7	5.1	5.0	**6.0**
Oct	3.8	3.6	3.7	3.8	3.8	3.9	4.0	3.8	3.5	4.0	5.2	6.1	6.7	7.4	7.6	7.7	7.3	6.5	6.1	5.7	5.0	4.3	4.1	3.8	**5.1**
Nov	3.7	3.7	3.8	3.9	4.1	4.1	4.0	3.5	3.4	3.7	4.7	5.7	6.3	6.7	6.9	7.0	6.5	5.8	5.1	4.9	4.6	4.1	3.9	3.9	**4.7**
Dec	3.9	4.0	4.1	4.2	4.2	4.3	4.1	3.9	3.8	3.5	3.9	4.5	5.2	5.7	6.1	6.2	5.9	5.5	5.1	5.0	4.6	4.4	4.2	3.9	**4.6**
Jan.-02	3.1	3.3	3.4	3.5	3.8	4.0	4.1	4.0	4.1	3.6	3.0	3.6	4.4	4.8	5.1	5.2	5.0	4.4	4.3	4.0	3.5	3.3	3.0	3.1	**3.9**
Feb	4.2	4.4	4.4	4.5	4.5	4.7	4.5	4.1	4.1	4.2	4.9	5.6	6.0	6.3	6.6	6.7	6.5	6.2	5.4	5.3	4.7	4.1	3.9	4.0	**5.0**
March	4.7	4.8	4.9	4.7	4.5	4.5	4.5	4.4	4.5	4.8	5.2	6.3	6.9	7.4	7.7	7.7	7.5	6.9	6.4	5.8	5.3	4.9	4.6	4.6	**5.6**
Apr	4.2	4.4	4.4	4.5	4.5	4.7	4.5	4.1	4.1	4.2	4.9	5.6	6.0	6.3	6.6	6.7	6.5	6.2	5.4	5.3	4.7	4.1	3.9	4.0	**5.0**
May	4.4	4.1	4.0	4.0	4.1	4.1	4.0	3.7	3.5	3.6	4.3	5.2	5.8	6.1	6.2	6.1	6.1	5.6	5.3	5.2	4.4	3.9	4.0	3.9	**4.7**
June	4.8	4.6	4.6	4.5	4.5	4.4	4.2	3.9	3.7	3.8	4.3	4.5	5.1	5.5	6.2	6.4	6.5	6.3	5.8	5.3	5.0	5.0	5.0	5.0	**4.9**
July	4.6	4.7	4.7	4.6	4.4	4.2	4.1	4.1	4.6	4.7	4.8	5.5	6.0	6.5	6.9	6.9	6.6	6.4	6.1	5.7	5.4	5.1	5.1	4.8	**5.3**
Average	**4.5**	**4.4**	**4.5**	**4.5**	**4.5**	**4.4**	**4.3**	**4.2**	**4.2**	**4.4**	**4.8**	**5.4**	**6.0**	**6.5**	**6.8**	**6.9**	**6.7**	**6.3**	**5.8**	**5.6**	**5.2**	**4.8**	**4.6**	**4.5**	**5.2**

Source: Dept. of Mechanical Engineering, KNUST

Table D-3. Hourly Monthly Mean Wind Speed (m/s) for Mankoadze at 12m (January 2001 to July 2002)

Hour Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Monthly Mean
Jan. 01	3.5	3.4	3.4	3.6	3.8	4.1	4.0	3.7	3.9	4.1	4.1	4.9	6.0	6.8	7.1	7.0	6.5	5.9	5.3	5.0	4.6	4.3	3.8	3.6	**4.7**
Feb	3.7	3.4	3.5	3.5	3.6	3.8	4.1	3.9	3.9	4.2	4.5	6.1	7.2	7.7	7.9	7.7	7.2	6.6	6.1	5.7	5.3	5.0	4.4	4.1	**5.1**
March	4.2	4.2	4.4	4.4	4.3	4.3	4.3	4.0	4.1	5.1	6.4	7.4	7.9	8.0	7.9	7.5	7.3	6.5	5.7	5.2	4.9	4.8	4.4	4.3	**5.5**
Apr	3.8	3.6	3.7	4.0	4.3	4.3	4.0	3.7	3.7	4.6	5.7	6.9	7.2	7.4	7.4	7.4	6.9	6.3	5.8	5.0	4.4	4.2	4.0	4.0	**5.1**
May	3.5	3.5	3.5	3.9	4.1	4.0	3.7	3.6	3.3	3.6	4.2	4.9	5.6	6.2	6.5	6.3	6.1	5.8	5.5	5.0	4.8	4.8	4.4	4.1	**4.6**
June	4.1	4.1	4.0	4.4	4.4	4.3	4.1	3.8	3.5	3.9	4.6	5.2	5.9	6.6	6.7	6.7	6.4	5.9	5.5	5.2	4.8	4.9	4.4	4.2	**4.9**
July	4.7	4.3	4.1	4.0	3.9	3.8	3.6	3.5	4.2	5.0	5.6	6.3	6.9	7.0	6.9	6.8	6.4	5.9	5.6	5.4	5.2	5.2	5.0	4.7	**5.2**
Aug	4.6	4.6	4.5	4.5	4.3	4.1	3.7	3.5	4.3	5.0	5.6	6.5	6.9	7.1	7.0	6.8	6.6	6.0	5.5	5.1	4.9	5.0	4.8	4.6	**5.2**
Sept	4.4	4.4	4.4	4.3	4.4	4.4	4.1	4.1	4.7	5.1	5.8	6.6	7.4	7.6	7.6	7.6	7.3	6.6	6.0	5.7	5.6	5.0	4.5	4.5	**5.5**
Oct	3.4	3.3	3.1	3.4	3.6	3.7	3.6	3.4	3.4	4.3	5.7	6.6	7.5	7.9	7.8	7.7	7.2	6.4	5.8	5.4	4.8	4.4	4.0	3.6	**5.0**
Nov	3.3	2.9	3.0	3.1	3.4	3.5	3.6	3.2	3.3	4.3	5.5	6.4	6.9	7.2	7.3	7.1	6.6	6.0	5.6	5.3	5.1	4.9	4.4	4.0	**4.8**
Dec	3.5	3.6	3.6	3.6	3.8	3.9	4.0	3.7	3.5	3.9	4.6	5.5	6.2	6.6	6.7	6.5	6.0	5.3	4.9	4.5	4.3	3.9	3.8	3.6	**4.6**
Jan. 02	2.9	2.9	2.9	3.1	3.4	3.7	3.9	3.7	3.4	3.3	3.6	4.5	5.6	6.3	6.5	6.2	5.4	4.7	4.2	3.9	3.5	3.4	3.3	3.1	**4.1**
Feb	3.9	3.7	3.8	4.0	3.9	4.1	4.2	4.2	4.4	5.0	5.8	6.7	7.5	8.1	8.2	7.9	7.4	6.6	5.8	5.4	5.2	5.1	4.9	4.4	**5.4**
March	5.9	6.2	6.5	6.8	6.5	6.4	6.4	5.7	5.9	7.0	8.8	10.3	11.7	11.7	11.7	11.9	11.0	9.9	8.9	7.9	7.4	6.8	6.6	6.3	**8.1**
Apr	8.6	8.7	9.3	9.4	9.0	9.2	9.9	8.6	9.2	10.6	12.4	14.4	16.0	15.9	15.4	15.7	15.1	14.0	12.6	11.6	11.1	9.6	8.7	9.2	**11.4**
May	8.5	8.9	9.0	9.2	8.9	9.1	9.0	7.8	7.6	8.8	11.2	13.5	15.1	15.5	15.9	15.2	14.8	13.9	13.2	12.5	11.2	10.1	8.7	8.7	**11.1**
June	10.1	10.1	10.2	9.4	9.3	9.6	9.8	8.9	8.0	8.3	10.1	11.9	12.5	13.9	14.8	15.0	15.0	14.1	12.6	11.5	11.2	11.1	10.3	10.2	**11.2**
July	9.2	8.5	8.5	8.5	8.6	8.5	8.3	8.1	9.0	9.9	10.9	12.5	13.7	14.5	14.4	14.0	13.7	12.2	11.1	10.6	10.4	10.0	9.8	9.6	**10.6**
Average	**5.0**	**5.0**	**5.0**	**5.1**	**5.1**	**5.2**	**5.2**	**4.8**	**4.9**	**5.6**	**6.6**	**7.7**	**8.6**	**9.1**	**9.1**	**9.0**	**8.6**	**7.8**	**7.1**	**6.6**	**6.3**	**5.9**	**5.5**	**5.3**	6.4

Source: Dept. of Mechanical Engineering, KNUST

Table D-4. Hourly Monthly Mean Wind Speed (m/s) for Warabeba at 12m (January 2001 to May 2002)

Hour / Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Monthly Mean
Jan. 01	2.5	1.8	1.8	1.8	1.7	1.8	1.8	2.0	2.6	2.8	3.4	4.3	5.5	5.9	6.1	6.1	5.9	5.6	5.3	4.8	4.4	4.2	3.8	3.1	**3.7**
Feb	3.4	2.7	2.3	2.1	2.1	2.3	2.5	2.5	2.9	3.2	3.8	5.1	6.0	6.3	6.7	6.6	6.5	6.1	5.9	5.6	5.0	4.7	4.4	4.1	**4.3**
March	2.5	2.4	2.3	2.2	2.3	2.3	2.2	2.5	2.7	4.2	5.0	5.9	6.4	6.5	6.7	6.5	6.3	5.8	5.3	5.0	4.6	4.2	3.7	3.1	**4.2**
Apr	2.6	2.1	2.0	1.9	2.3	2.3	2.4	2.6	2.8	3.6	4.5	5.7	6.0	6.1	6.3	6.3	6.1	5.7	5.5	4.7	4.0	3.6	3.0	2.7	**3.9**
May	2.6	2.2	1.9	2.1	2.6	2.4	2.2	2.3	2.2	2.6	3.4	4.0	4.7	5.2	5.5	5.5	5.5	5.5	5.1	4.6	4.3	3.7	3.3	3.0	**3.6**
June	2.4	2.3	2.3	2.5	2.5	2.3	2.2	2.6	2.5	3.0	3.8	4.7	5.1	5.9	6.1	6.0	5.9	5.6	5.3	4.9	4.4	4.0	3.7	3.3	**3.9**
July	2.9	3.0	2.9	3.0	2.8	2.8	2.9	2.5	3.2	3.7	4.2	4.6	4.7	5.1	5.4	5.3	5.0	4.6	4.1	3.6	3.6	3.5	3.3	3.1	**3.7**
Aug	2.2	2.0	2.0	2.0	1.7	1.6	1.7	1.9	2.2	3.0	3.6	4.1	4.7	4.8	4.7	4.7	4.5	4.0	3.3	2.8	2.4	2.1	1.7	2.1	**2.9**
Sept	2.4	2.5	2.4	2.2	2.4	2.2	2.1	2.5	3.3	4.0	4.8	5.5	6.2	6.5	6.4	6.4	6.3	5.8	4.9	4.4	3.9	3.3	2.9	2.4	**4.0**
Oct	2.7	2.0	1.9	1.7	1.8	1.8	1.8	2.2	2.6	4.0	5.0	5.9	6.5	7.1	7.3	7.3	7.1	6.6	6.2	5.8	5.2	4.6	3.8	3.2	**4.3**
Nov	2.9	2.1	1.9	1.9	1.9	2.0	2.1	2.0	2.0	3.1	4.2	5.2	5.8	6.2	6.5	6.4	6.2	6.0	5.7	5.3	5.0	4.7	4.4	3.8	**4.1**
Dec	1.6	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2.1	2.6	3.4	4.3	5.1	5.5	5.8	5.7	5.4	5.0	4.8	4.5	4.2	3.5	2.6	2.0	**3.3**
Jan. 02	2.1	1.9	1.7	1.7	1.9	1.9	2.0	2.1	2.5	2.4	2.7	3.8	4.8	5.3	5.3	5.3	4.8	4.1	3.6	3.3	3.2	2.8	2.7	2.4	**3.1**
Feb	3.4	3.0	2.6	2.6	2.5	2.6	2.6	2.8	3.2	4.1	4.8	5.8	6.5	7.0	7.2	7.1	6.9	6.3	5.7	5.3	5.0	4.6	4.4	3.9	**4.6**
March	2.7	2.3	2.4	2.3	2.1	1.8	1.7	2.2	3.1	4.1	5.3	6.3	6.9	7.2	7.2	7.3	7.1	6.7	6.0	5.5	4.8	4.1	3.8	3.0	**4.4**
Apr	2.2	1.7	1.8	2.0	1.8	1.7	2.1	2.1	2.7	3.6	4.5	5.3	5.9	6.1	6.1	6.4	6.3	6.1	5.4	4.8	4.5	3.7	2.9	2.6	**3.8**
May	2.2	2.2	2.0	1.9	2.0	1.9	1.9	2.1	2.1	2.9	4.1	5.1	5.7	6.0	6.4	6.3	6.2	6.1	5.9	5.6	5.2	4.4	3.3	3.0	**3.9**
Average	**2.5**	**2.2**	**2.1**	**2.1**	**2.1**	**2.1**	**2.1**	**2.3**	**2.6**	**3.3**	**4.1**	**5.0**	**5.7**	**6.1**	**6.2**	**6.2**	**6.0**	**5.6**	**5.2**	**4.7**	**4.3**	**3.9**	**3.4**	**3.0**	3.9

Source: Dept. of Mechanical Engineering, KNUST

Source: Dept. of Mechanical Engineering, KNUST

Table D-6. Hourly Monthly Mean Wind Speed (m/s) for Adafoah at 12m (July 1999 to August 2000)

Hour / Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Monthly Mean
Jul. 99	4.8	4.8	4.8	5.0	4.9	4.4	4.5	4.2	4.3	4.3	4.5	4.8	4.9	5.1	5.5	6.0	5.9	5.5	5.1	4.6	4.5	4.6	4.6	4.6	**4.8**
Aug																									
Sept	5.5	5.7	5.9	5.8	5.6	5.5	5.4	5.2	5.1	5.3	5.5	6.0	6.4	6.7	7.1	7.0	6.6	5.9	5.3	5.1	4.7	4.6	4.8	5.2	**5.7**
Oct	5.9	6.1	6.5	6.2	6.0	5.9	5.6	5.8	5.7	5.7	6.4	6.8	7.1	7.3	7.5	7.4	7.2	6.6	6.4	5.9	5.8	5.7	5.7	5.8	**6.3**
Nov	4.8	4.9	4.9	4.5	4.3	4.0	3.7	3.7	4.1	4.4	4.6	5.2	5.8	6.1	6.2	6.1	5.9	5.7	5.4	5.3	5.2	5.1	5.0	4.8	**5.0**
Dec	4.3	4.4	4.5	4.0	3.4	2.7	2.7	2.6	2.9	3.3	3.7	4.0	4.6	5.1	5.4	5.4	5.4	5.2	5.0	4.9	4.7	4.6	4.5	4.4	**4.2**
Jan.-00	5.0	5.1	5.1	5.2	4.9	4.7	4.6	4.2	4.5	4.5	4.5	4.8	5.5	6.0	6.2	6.3	6.2	5.8	5.5	5.3	5.0	4.8	4.8	4.8	**5.1**
Feb	4.5	4.7	4.6	4.6	4.2	4.1	4.1	4.0	4.4	4.7	4.7	4.9	5.5	6.2	6.5	6.5	6.3	6.1	5.8	5.4	4.7	4.2	4.0	4.1	**5.0**
March	5.6	5.6	5.6	5.5	5.6	5.1	4.6	4.2	4.4	4.4	4.8	5.3	5.8	6.3	6.8	7.1	7.3	7.2	6.8	6.5	6.2	6.0	5.9	5.8	**5.8**
Apr																									
May	4.7	4.8	4.6	4.4	4.1	3.8	3.7	4.5	4.6	4.6	4.8	4.7	5.0	5.3	5.7	6.0	6.0	6.0	5.8	5.5	5.1	5.1	5.1	4.9	**4.9**
June	5.9	6.0	5.8	5.7	5.4	5.0	4.4	4.9	4.9	5.1	5.1	5.4	5.9	6.4	6.4	6.1	6.3	6.2	6.0	6.0	5.7	5.5	5.3	5.6	**5.6**
July	4.7	4.9	5.1	5.2	4.9	4.9	5.0	4.8	4.6	4.7	5.2	5.3	5.6	6.1	6.4	6.7	6.5	6.2	5.8	5.5	5.2	5.0	4.8	4.8	**5.3**
Aug	5.0	5.3	5.3	5.0	4.9	4.9	4.9	4.7	4.6	4.7	4.9	5.4	5.7	5.9	6.0	6.0	5.8	5.7	5.6	5.2	5.0	4.8	4.6	4.8	**5.2**
Average	**5.1**	**5.2**	**5.2**	**5.1**	**4.9**	**4.6**	**4.4**	**4.4**	**4.5**	**4.7**	**4.9**	**5.2**	**5.6**	**6.0**	**6.3**	**6.4**	**6.3**	**6.0**	**5.7**	**5.4**	**5.2**	**5.0**	**4.9**	**5.0**	5.3

Source: Dept. of Mechanical Engineering, KNUST

Table D-7. Hourly Monthly Mean Wind Speed (m/s) for Lolonya at 12m (July 1999 to August 2000)

Hour / Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Monthly Mean
Jul. 99	4.8	4.7	4.8	4.8	4.7	4.3	4.2	4.2	4.3	4.3	4.7	5.1	5.2	5.5	5.8	6.2	5.9	5.4	5.1	4.8	4.7	4.7	4.6	4.6	**4.9**
Aug	5.1	5.4	5.3	5.3	5.1	4.9	4.7	4.5	4.3	4.6	5.2	5.9	6.3	6.5	6.4	6.4	6.2	5.8	5.4	5.3	5.0	4.7	4.7	4.9	**5.3**
Sept	7.1	7.2	7.2	6.4	6.0	5.4	5.2	5.0	5.4	5.7	6.3	6.8	7.2	7.4	7.7	7.8	7.4	6.7	6.1	5.4	5.0	5.9	6.6	7.4	**6.4**
Oct	6.1	6.3	6.2	6.1	5.8	5.6	5.5	5.7	5.7	5.8	6.5	6.9	7.3	7.6	7.6	7.4	7.1	6.8	6.4	6.2	6.0	6.0	6.0	5.9	**6.4**
Nov	4.9	4.8	4.5	4.2	3.8	3.7	3.5	4.0	4.4	4.7	5.1	5.7	6.4	6.7	6.7	6.5	6.2	5.9	5.5	5.5	5.3	5.1	4.9	4.9	**5.1**
Dec	4.4	4.2	3.9	3.3	2.9	2.9	2.9	3.1	3.4	3.5	3.9	4.3	4.8	5.4	5.7	5.7	5.5	5.4	5.2	4.9	4.7	4.5	4.4	4.4	**4.3**
Jan.-00	4.9	5.0	5.1	5.0	4.6	4.1	4.0	4.0	4.3	4.3	4.6	5.0	5.8	6.4	6.6	6.5	6.3	5.8	5.6	5.3	5.0	4.7	4.6	4.7	**5.1**
Feb	4.4	4.6	4.4	3.9	3.9	4.0	3.9	4.3	4.7	5.1	5.1	5.2	6.0	6.7	7.1	7.1	6.8	6.5	5.9	5.2	4.6	4.1	3.9	4.1	**5.1**
March	5.6	5.7	5.7	5.5	5.4	4.7	4.2	4.3	4.5	4.6	5.2	5.7	6.5	6.9	7.3	7.6	7.6	7.3	6.9	6.6	6.2	6.0	5.9	5.8	**5.9**
Apr	5.6	5.5	5.3	5.4	5.4	5.1	5.0	5.5	5.5	5.4	5.8	6.2	6.2	6.5	6.7	6.7	6.7	6.6	6.4	6.1	6.0	5.5	5.3	5.2	**5.8**
May	4.7	4.4	4.5	4.1	3.8	3.8	4.0	4.5	4.6	4.3	4.9	5.0	5.4	5.7	6.3	6.5	6.4	6.2	5.9	5.8	5.7	5.3	5.3	5.0	**5.1**
June	5.9	5.8	5.6	5.3	5.1	4.6	4.4	4.8	5.0	5.1	5.2	5.5	6.1	6.5	6.6	6.2	6.4	6.4	6.1	6.1	5.8	5.5	5.4	5.5	**5.6**
July	5.1	5.1	5.3	5.1	5.0	5.0	4.9	4.8	4.7	4.9	5.3	5.7	6.1	6.4	6.7	6.7	6.7	6.3	5.8	5.5	5.2	5.1	5.0	5.0	**5.5**
Aug	5.5	5.7	5.5	5.1	4.9	4.7	4.6	4.6	4.9	5.2	5.5	5.9	6.2	6.4	6.3	6.2	6.1	6.0	5.7	5.3	5.2	5.0	5.1	5.2	**5.4**
Average	**5.3**	**5.3**	**5.2**	**5.0**	**4.7**	**4.5**	**4.4**	**4.5**	**4.7**	**4.8**	**5.2**	**5.6**	**6.1**	**6.5**	**6.7**	**6.7**	**6.5**	**6.2**	**5.9**	**5.6**	**5.3**	**5.2**	**5.1**	**5.2**	5.4

Source: Dept. of Mechanical Engineering, KNUST

Table D-8. Hourly Monthly Mean Wind Speed (m/s) for Kpone at 12m (July 1999 to August 2000)

Hour / Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Monthly Mean
Aug. 99	4.1	3.8	3.7	3.4	3.3	3.2	3.4	4.6	5.3	5.9	6.8	6.9	7.0	6.9	6.7	6.5	6.2	5.7	5.5	5.2	5.0	4.6	4.5	4.4	**5.1**
Sept	4.3	3.9	3.7	3.8	3.6	3.3	3.6	4.8	5.4	5.9	7.0	7.6	7.6	7.6	7.5	7.2	6.8	6.4	5.8	5.4	5.0	4.6	4.5	4.3	**5.4**
Oct	3.8	3.7	3.6	3.5	3.3	3.2	3.8	5.0	5.2	5.8	6.8	7.5	7.9	8.0	7.9	7.4	7.1	6.7	6.0	5.5	5.0	4.7	4.3	3.9	**5.4**
Nov	2.8	3.0	2.9	2.7	2.7	2.9	3.0	3.5	4.2	5.1	5.9	6.5	6.8	6.9	6.8	6.6	6.0	5.7	5.4	4.8	4.4	3.9	3.4	3.3	**4.6**
Dec	2.7	2.8	2.8	2.8	2.8	2.8	2.7	3.0	3.2	3.5	4.4	5.1	5.5	5.7	5.8	5.7	5.4	4.9	4.7	4.2	3.7	3.4	3.1	2.9	**3.9**
Jan.-00	3.2	3.1	3.2	3.1	3.0	2.8	2.9	3.4	4.3	4.4	4.9	5.9	6.3	6.5	6.5	6.2	6.0	5.5	4.9	4.5	3.9	3.4	3.3	3.3	**4.4**
Feb	3.3	3.1	2.8	2.6	2.6	2.7	2.7	3.4	4.6	5.2	5.6	6.1	6.4	6.7	6.7	6.6	6.1	5.6	4.8	4.2	3.5	3.3	3.3	3.1	**4.4**
March	4.1	3.8	3.7	3.4	3.3	3.2	2.8	3.6	3.9	4.6	5.9	6.6	7.0	7.2	7.4	7.5	7.4	7.2	6.7	6.2	5.7	5.1	5.0	4.6	**5.2**
Apr	3.5	3.3	3.0	2.9	2.9	3.0	3.4	4.5	5.3	5.8	6.7	7.3	7.2	7.4	7.4	7.1	6.9	6.4	5.9	5.4	5.0	4.3	3.9	3.6	**5.1**
May	3.0	2.9	2.9	2.8	3.1	2.6	3.2	4.7	5.0	5.4	5.6	6.2	6.7	7.2	7.4	7.3	6.9	6.5	6.1	5.5	5.3	4.6	3.4	3.0	**4.9**
June	3.4	3.4	3.2	3.2	3.2	2.9	2.8	3.7	4.3	4.8	5.3	5.9	6.2	6.0	6.5	6.3	5.9	5.7	5.2	5.1	4.6	4.1	3.8	3.4	**4.5**
July	3.9	3.9	3.8	3.7	3.7	3.5	3.6	4.4	5.2	6.0	6.7	7.1	7.2	7.1	6.9	6.8	6.5	6.2	5.7	5.1	4.9	4.5	4.3	4.2	**5.2**
Aug	4.7	4.5	4.2	4.1	3.7	3.6	3.7	4.4	5.1	5.7	6.6	6.8	7.0	7.1	7.0	6.5	6.3	6.2	5.5	5.3	5.1	4.9	4.9	4.9	**5.3**
Average	**3.6**	**3.5**	**3.3**	**3.2**	**3.2**	**3.0**	**3.2**	**4.1**	**4.7**	**5.2**	**6.0**	**6.6**	**6.8**	**7.0**	**7.0**	**6.7**	**6.4**	**6.1**	**5.6**	**5.1**	**4.7**	**4.3**	**4.0**	**3.8**	4.9

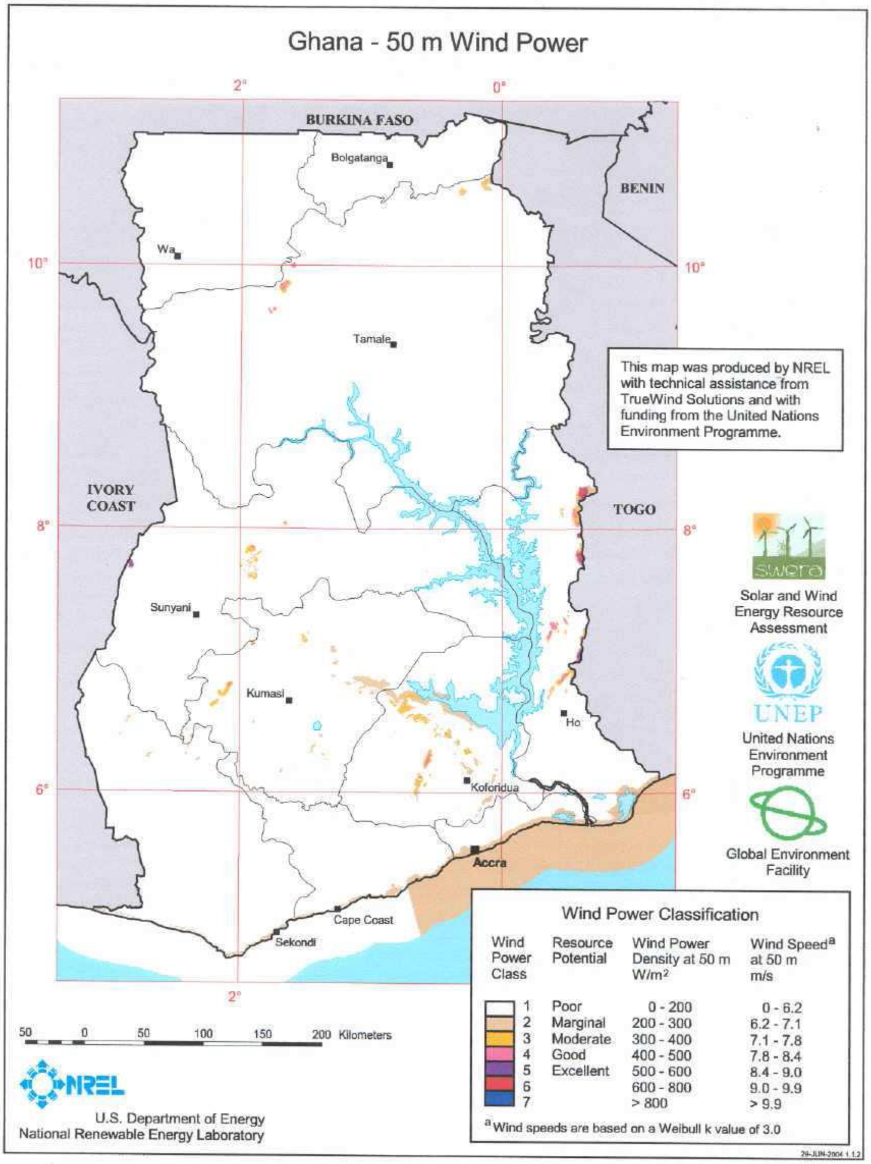
Source: Dept. of Mechanical Engineering, KNUST

Table C-3. Monthly mean wind speed (m/s) at 12 m for all the 22 MSD Synoptic Stations

EXTRAPOLATED MONTHLY MEAN WIND SPEED (m/s) @ 12 m (1995 - 2002)

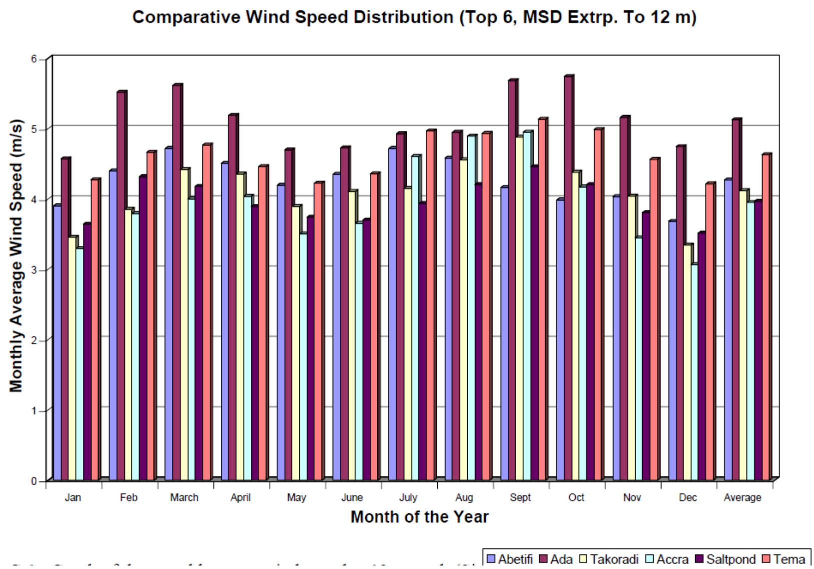
Station	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Average
Abetifi	3.9	4.4	4.7	4.5	4.2	4.4	4.7	4.6	4.2	4.0	4.0	3.7	**4.3**
Accra	3.3	3.8	4.0	4.0	3.5	3.7	4.6	4.9	5.0	4.2	3.4	3.1	**4.0**
Adafoah	4.6	5.5	5.6	5.2	4.7	4.7	4.9	4.9	5.7	5.7	5.2	4.7	**5.1**
Akatsi	2.6	2.9	2.9	2.8	2.5	2.5	3.3	3.5	3.3	2.6	2.2	2.6	**2.8**
Akim Oda	2.3	2.5	3.0	3.1	2.4	2.4	3.0	2.8	2.8	2.5	3.3	2.7	**2.7**
Akuse	3.5	4.1	4.4	4.4	3.7	3.5	4.1	4.3	4.0	3.4	3.0	3.2	**3.8**
Axim	2.9	3.4	3.6	3.4	3.2	3.5	3.5	3.4	3.5	3.6	3.3	3.1	**3.4**
Bekwai	2.0	2.2	2.3	2.2	2.1	2.0	2.1	2.2	2.2	2.1	2.1	2.0	**2.1**
Bole	3.3	3.5	3.7	3.6	3.2	2.9	3.0	2.6	2.1	2.3	2.6	3.1	**3.0**
Ho	2.5	2.7	2.8	2.7	2.5	2.5	2.5	2.5	2.5	2.4	2.4	2.4	**2.5**
Koforidua	2.3	2.4	2.5	2.4	2.4	2.4	2.5	2.6	2.5	2.4	2.3	2.2	**2.4**
Krachi	2.8	3.4	3.7	3.6	3.2	2.8	2.8	2.6	2.5	3.0	2.6	2.5	**2.9**
Kumasi	3.2	3.8	4.2	4.0	3.7	3.7	4.4	4.3	4.1	3.6	3.4	3.2	**3.8**
Navorongo	3.6	3.7	3.1	3.2	3.2	2.9	2.8	2.8	2.6	2.7	2.8	3.3	**3.0**
Saltpond	3.6	4.3	4.2	3.9	3.7	3.7	3.9	4.2	4.5	4.2	3.8	3.5	**4.0**
Sunyani	3.5	3.9	4.4	4.2	3.8	3.9	4.1	4.1	3.7	3.5	3.4	3.4	**3.8**
Takoradi	3.5	3.9	4.4	4.4	3.9	4.1	4.2	4.6	4.9	4.4	4.0	3.3	**4.1**
Tamale	4.1	4.6	4.7	4.9	4.3	3.9	4.0	3.6	3.0	3.1	3.3	3.8	**3.9**
Tema	4.3	4.7	4.8	4.5	4.2	4.4	5.0	4.9	5.1	5.0	4.6	4.2	**4.6**
Wa	3.9	4.1	3.8	4.0	3.7	3.5	3.3	2.7	2.3	2.8	2.9	3.2	**3.3**
Wenchi	3.4	3.7	4.1	3.9	3.7	3.7	3.7	3.7	3.5	3.1	3.1	3.1	**3.6**
Yendi	2.9	3.2	3.0	3.2	3.0	2.8	2.8	2.7	2.4	2.4	2.3	2.7	**2.8**

Source: Dept. of Mechanical Engineering, KNUST



Wind Potential of Ghana

Source: NREL, US Department of Energy



Graph of monthly mean wind speed at 12m six locations in Ghana.

Appendix A- 5: Population Census Data of Ghana

Region	Size (sq.m)	Population	% of total	Population of Case Study Areas
Ashanti	24,389	4,780,380	19.4	130,795
Greater Accra	3,245	4,010,054	16.3	
Eastern	19,323	2,633,154	10.7	
Northern	70,384	2,310,983	10.1	
Western	23,921	2,376,021	9.6	
Brong Ahafo	39,557	2,317,292	9.4	81,000
Central	9,826	2,201,863	8.9	
Volta	20,570	2,118,252	8.6	2,118,252
Upper East	8,842	1,046,545	4.2	
Upper West	18,476	702,110	2.8	

Ghana Population Census. 2010

Facility	No.	%	Western	Central	GT. Accra	Volta	Eastern	Ashanti	BA	Northern	UE	UW
Household with Fixed Lines	127,694	2.3	11,574	7,595	52,276	6,141	9,249	27,809	4,896	2,696	1,728	730
Household with Desktop/ Laptop	431,917	7.9	36,214	28,167	174,285	15,054	32,554	104,197	22,618	9,312	5,490	4,026
12Yrs + having internet	1,312,9171	7.8	103,166	104,301	555,847	50,644	88,869	295,251	52,923	32,128	15,777	13,065
12Yrs + having Mobile phones	8,049,408	47.7	750,227	669,083	2,191,910	540,623	806,291	1,859,656	622,715	341,536	167,421	99,946

Appendix A- 6: Solar PV Companies and their Location in Ghana

SOLAR PV COMPANIES AND THEIR LOCATIONS IN GHANA

NAME OF COMPANY	**LOCATION**
Solar Light Co.	Accra
Danafco Engineering (DENG)	Accra
S.U.N Solar Ltd	Accra
Solarco Ltd	Accra
Gold River Solar Electric	Accra
Solar Power Co.	Kumasi
B.E.S.T Solar Co.	Tamale

EXAMPLES OF SOLAR PV HOME SYSTEMS' PRICE PACKAGES IN GHANA

Solar Home Lighting Systems

Solar Home Systems are a cost effective and reliable way to provide power for lighting and small home appliances. They ensure that you get power nearly 100% of the time, better than any current alternative. These systems are also modular and can be expanded with your operations or extended to nearby premises at anytime.

Small Home Lighting System

Appliances	Rating	Quantity	Hrs/Day	Days/Wk
Outside Lights	20watt	1	12hrs	7 days
Small TV Set	40watt	1	3hrs	7 days
Interior Lights	15watt	4	5hrs	7 days

Small Home System Features

- 2 Solar Panels
- 2 Deep Cycle Batteries
- 1 LVD Charge Controller
- 1 Inverter
- Mountings, switches, cabling and installation

PRICE: $ 2,500

Standard Home Backup System (3 Bedroom House)

Appliances	Rating	Quantity	Hrs/Day	Days/Wk
Outside Lights	20watt	2	12hrs	1 day
Interior Lights	15	8	5hrs	1 day
Stereo	50	1	6hrs	1 day
TV Set	80	1	6hrs	1 day

Standard Home System Features

- 2 Solar Panels
- 4 Deep Cycle Batteries
- 1 LVD Charge Controller
- 1 Inverter
- Mountings, switches, cabling and installation

PRICE: $4,200

Deluxe Backup System (4/5 Bedroom House)

Appliances	Rating	Quantity	Hrs/Day	Days/Wk
Outside Lights	20watt	4	12hrs	1 day
Utility Lights	15	4	6hrs	1 day
Interior Lights	15	15	5hrs	1 day
Stereo	50	1	6hrs	1 day
TV Set	80	2	6hrs	1 day
Fridge	200	1	6hrs	1 day
Freezer	200	1	6hrs	1 day

Deluxe Backup System Features

- 2 Solar Panels
- 8 Deep Cycle Batteries
- 1 LVD Charge Controller
- 1 Inverter
- Mountings, switches, cabling and installation

PRICE: $5,800

Superior Hybrid System (4/5 Bedroom House)

Appliances	Rating	Quantity	Hrs/Day	Days/Wk
Outside Lights	20watt	2	12hrs	7 days
Interior Lights	15	10	5hrs	7 days
Stereo	50	1	6hrs	1 day
TV Set	80	1	6hrs	1 day
Fridge	200	1	6hrs	1 day

Superior Hybrid System Feathures

- 2 Solar Pan els
- 12 Deep Cycle Batteries
- 1 Inverter with LVD Charge Controller
- Mountings, switches, cabling and installation

PRICE: $8,100

Notes:

- All prices are indicative only, and are for complete and installed systems.
- Additional panels may be needed if the system is used for more days than those indicated.
- Additional batteries are needed if more appliances are to be used. A larger inverter may also be required.

SOLAR LIGHT Co.

Solar Light Company Ltd.
60 Faanofa Rd., Kokomlemle, Accra
P. O. Box 11241 Accra-North, Ghana
Phone (233-21) 234349, Fax 245675
E-mail: solar@africaonline.com.gh
Website: www.solar-light.com

Appendix A- 7: Weather Data of Selected Study Sites in Ghana

Techiman, Ghana - Solar energy and surface meteorology				Lat. 7.58 (70, 34' 48" N), Lon. -1.94 (10,56'24"W)								
Variable	Jan	Feb.	Mar	Apr.	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Insolation, kWh/m²/day	6.11	6.33	6.29	6.06	5.72	5.01	4.57	4.34	4.67	5.38	5.71	5.86
Clearness, 0 - 1	0.68	0.65	0.61	0.58	0.56	0.5	0.45	0.42	0.46	0.55	0.62	0.67
Temperature, °C	27.14	27.55	27.44	26.63	26.3	25.27	24.43	24.38	24.92	25.69	26.7	26.88
Wind speed, m/s	2.81	2.54	3.18	2.84	3.22	2.88	2.9	2.79	2.53	2.52	2.7	2.74
Precipitation, mm	8	40	114	134	160	175	131	95	187	176	50	18
Wet days, d	4	6.3	11.9	13.2	16.2	18.9	17.1	15.4	23.1	22.2	8.8	4.9
These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002												

Ho, Ghana - Solar energy and surface meteorology			Lat. 6.6 (60 36"N), Lon. 0.47 (00, 28' 12" E)									
Variable	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Insolation, kWh/m²/day	6.09	6.29	6.09	5.82	5.4	4.69	4.23	4.14	4.38	4.95	5.52	5.69
Clearness, 0 - 1	0.66	0.64	0.59	0.56	0.53	0.47	0.42	0.4	0.43	0.5	0.59	0.64
Temperature, °C	26.93	27.02	26.57	26.09	25.83	24.96	24.12	24.21	24.63	25.06	25.75	26.4
Wind speed, m/s	3.26	2.91	3.4	2.86	3.15	2.7	3.19	3.28	3.27	2.84	3.1	2.71
Precipitation, mm	19	52	109	131	160	196	137	94	155	155	56	30
Wet days, d	4.6	7.4	12	13.2	15.8	19.2	15.5	13.7	17.8	18.1	8.9	6.6
These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002												
Notes: Help. Change preferences.												

Ada Foah (ADA)	Lat. 5.783/ Lon. 0.633												
Statistics based on observations taken between 10/2010 - 11/2012 daily from 7am to 7pm local time.													
Month of year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
Insolation, kWh/m2/day	5.78	6.09	5.94	5.72	5.32	4.71	5.2	5.31	5.29	5.64	5.69	5.56	
Dominant Wind dir.	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw	sw
Wind probability	2	1	5	13	8	7	5	4	7	2	4	6	5
> = 4 Beaufort (%)													
Av.	6	7	8	8	8	8	8	7	8	8	7	7	7
Wind speed													
(Knots)													
Average air temp. (°C)	29	30	31	30	30	27	27	26	27	29	30	30	28

Appendix B: Interview Questions

Appendix B - 1: Interview Questions for Mobile Phone Operators in Ghana

1. Please briefly describe your responsibilities in your company.

2. Does your company mobile phone network cover the entire country (Ghana)?

3. What type of mobile phone network equipment is your company using?

4 Do you have the national electricity grid at all your cell sites?

5 What other forms of power supply do you have at the cell sites and why? (if any).

6 How do you monitor energy consumption of the mobile phone network?

7 What is the annual energy consumption of the mobile phone network in your company?

8 What is the breakdown in consumption of component (units)?

9 What challenges does your company have with electricity supply to the mobile phone network?

10 How often your company does experiences power outages at a mobile phone network?

11 How does the outage affect the operation of your mobile phone network?

12 Has the electricity supply and energy consumption of the mobile phone network been discussed in your company?

13 How would you expect the energy consumption of the mobile phone network to change in the future?

14 How will your company welcome the use of sustainable energy (e.g. Solar) in the mobile phone network?

15 Will your company expect some incentives (e.g. tax, etc) from the government?

16 What do you think are the environmental impacts of your company's activities?

17 Is there any one in your company responsible for environmental affairs?

18 Have your customers and/or general public shown concern in your company's environmental affairs?

19 Do you please have any other comment concerning this interview?

Thank you.

Appendix B -2: Interview Questions for Key Energy Institutions/ Stakeholders (EC – GH, MOE – GH, VRA, ECG, MOEN – GH).

1. Please briefly describe your responsibilities in your company.

2. What are the functions of this institution in the provision of electricity to the citizens of Ghana?

3. What are the government energy policies towards the urban and rural areas of Ghana?

4. What forms of energy programmes are promoted within the country?

5. What is the rationale behind the strong advocacy for renewable energy use in Ghana?

6. What is the Ghanaian perception about the use of renewable energy (Photovoltaic) as compared to other technologies?

7. Do these perceptions about use of photovoltaic technology influence its adoption?

8. What are the available institutional structures in place as far as the development of photovoltaic energy technology is concerned in Ghana.

9. How adequate are these institutional structures?

10 What regulatory framework supervises the trade and use of photovoltaic energy technology in Ghana?

11 How adequate are these regulatory frameworks, which oversee the dealership/market of photovoltaic technology In Ghana?

12 What is the performance of existing market models?

13 Do you please have any other comment concerning this interview?

Thank you.

Appendix B - 3: Questionnaire for Opinion Leaders in the selected study sites in Ghana

Date of Interview Questionnaire Number

Name of Study Site

Interviewer

Please provide some information about yourself by responding to these questions.

1. Sex of respondent M( ) F( )

2. Age of respondent 25 – 35 ( )

36 – 45 ( )

46 – 55 ( )

56 – 65 ( )

3. What is your level of educational?

Primary School ( )

Middle School ( )

Secondary School ( )

Training College ( )

Advanced/University ( )

Never been to school ( )

Other (Specify) ……………………………………………………………

4. What is your marital status Single ( )

Married ( )

Divorce ( )

Widow /widower ( )

5. What is your religion?

Christian ( )

Islam ( )

Traditionalist ( )

Others ( )

6. Do you have mobile phone? Yes ( ) No ( )

7. Does your phone functions every time?

Yes ( )

No ( )

8. Would you like Telecom Company to improve the quality of their services?

Yes ( )

No ( )

9. Does the Telecom operator visit your town every week?

Yes ( )

No ( )

10. Do you know the type of electricity source the telecom company uses?

Yes ( )

No ( )

11. Which of these forms of electricity generation sources does the telecom company use in your town?

National Grid ( )

Diesel Gen Set ( )

Solar PV ( )

Wind Energy ( )

12. Does the noise from telecom generator disturb you?

Yes ( )

No ( )

13. Do people steal from the telecom company?

Yes ( )

No ( )

14. What do they steal?

Diesel fuel ( )

Engine Oil ( )

Battery ( )

15. Will you prefer that the telecom company uses different form of electricity?

Yes ( )

No ( )

16. What type of electricity source will you prefer?

National Grid ( )

Diesel Gen Set ( )

Solar PV ( )

Wind Energy ( )

Appendix B - 4: Sample Response

1. Please briefly describe your responsibilities in your company?

Manages the IP/MPLS network which serves as the backbone for Layer 2 and 3 services (including Internet, Backhauling of BTs and Node Bs, etc)

2. Does your company mobile phone network cover the entire country (Ghana)?

YES

3. What type of mobile phone network equipment is your company using?

GSM

4. Do you have the national electricity grid at all your cell sites?

NO

5. What other forms of power supply do you have at the cell sites and why?

INVERTERS ON BATTERY BACKUPS & DIESEL ENGINES

6. How do you monitor energy consumption of the mobile phone network?

SOFTWARE, via REMOTE MONITORING

7. What is the annual energy consumption of the mobile phone network in your company?

Not sure

8. What is the breakdown in consumption of component (units)?

BS RADIO approx. 70%, Transceivers, Muxes & Others 30%

9. What challenges does your company have with electricity supply to the mobile phone network?

Unreliable Grid Supply

10. How often your company does experiencing power outages at a mobile phone network?

Currently every other day for nearly 12hrs outage

11. How does the outage affect the operation of your mobile phone network?

Unplanned expenditures on fuel off the budgets

12. Has the electricity supply and energy consumption of the mobile phone network been discussed in your company?

Yes at various workshops and seminars

13. How would you expect the energy consumption of the mobile phone network to change in the future?

To have cheaper and reliable backup power supply

14. How will your company welcome the use of sustainable energy (e.g. Solar) in the mobile phone network?

It will be welcome if it will be cost effective

15. Will your company expect some incentives (e.g. tax, etc) from the government?

YES

16. What do you think are the environmental impacts of your company's activities?

Electromagnetic wave emission

17. Is there any one in your company responsible for environmental affairs?

YES

18. Have your customers and/or general public shown concern in your company's environmental affairs?

Yes (National communication authority)

19. Do you please have any other comment concerning this interview?

NO

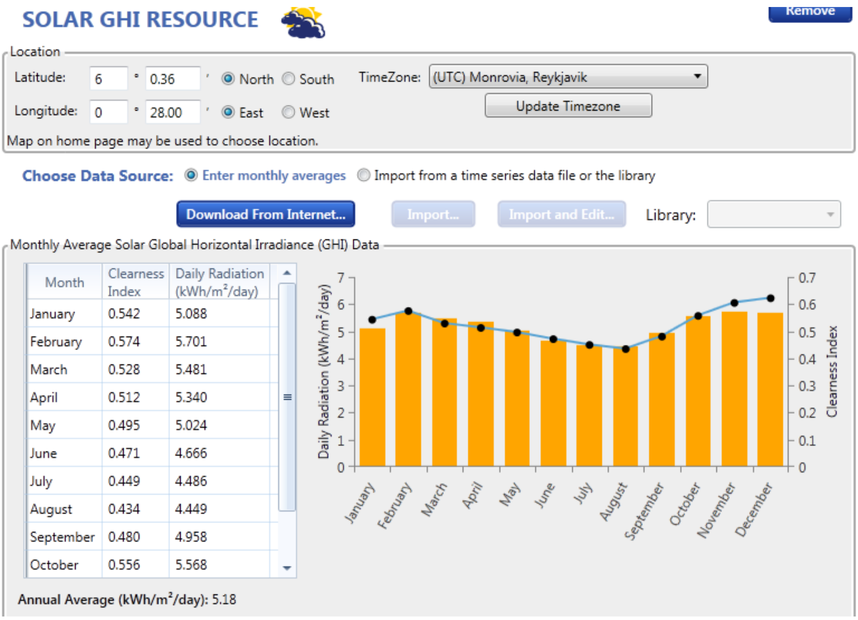
Thank you.

Appendix C: List of Anonymised Key Informants and Interviewees

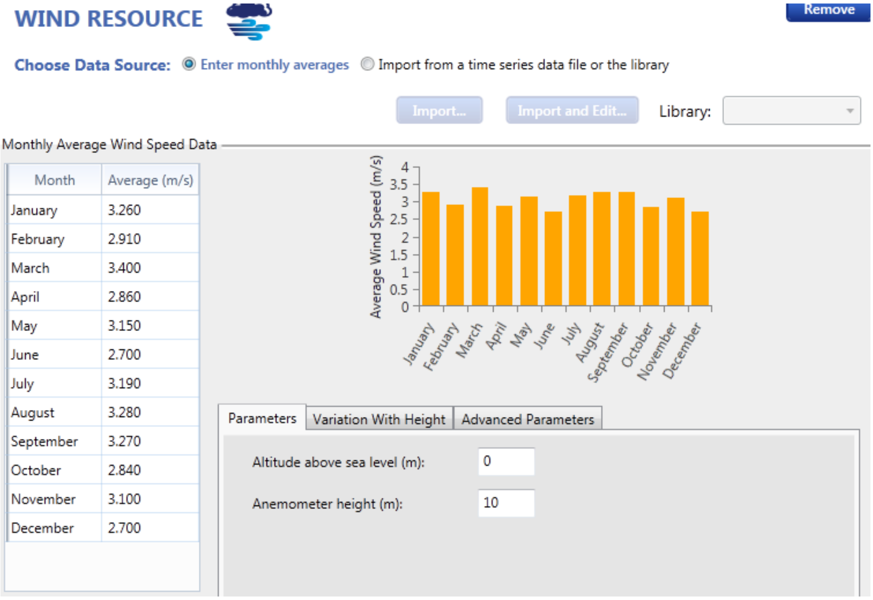
Organizations	Anonyms of Interviewees
Ministry of Energy, Ghana (MOE-GH)	Senior Civil Servants
Energy Commission, Ghana (EC-GH)	Senior Civil Servants
Ministry of Environment (MOEn.-GH)	Senior Civil Servants
Vodafone- Ghana	Engineers and Top management personnel
MTN- Ghana	Top management personnel
Airtel- Ghana	Engineers and Top management personnel
Tigo-Ghana	Top management personnel
Solar Light Company, Ghana	Spokesman

Appendix D: HORMER Software Simulation Results

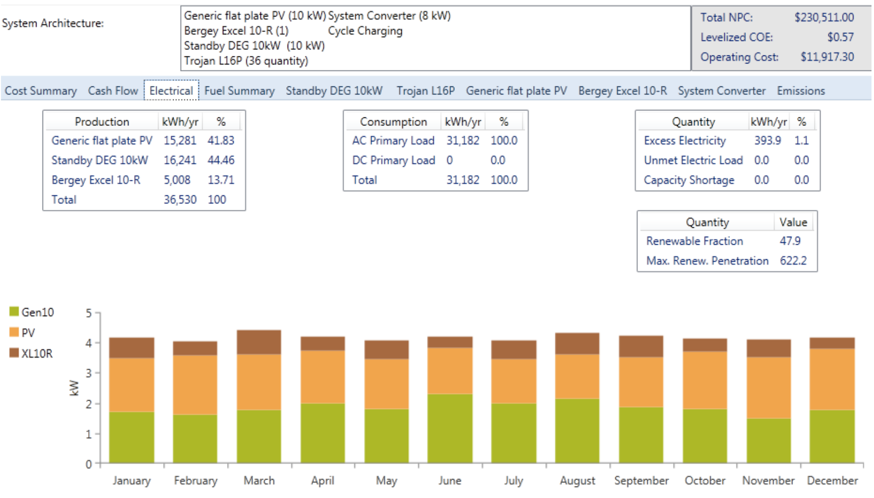
Appendix D - 1: HORMER Software Simulation Results for Kabakaba Hill (Ho)



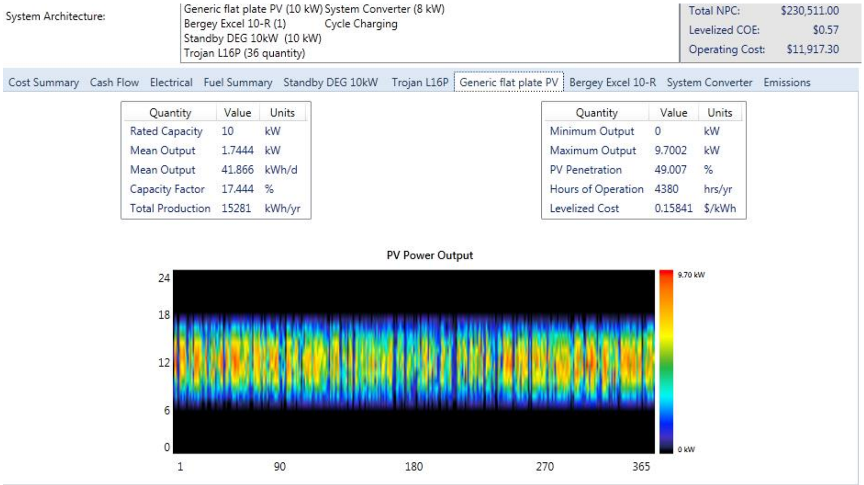
Solar Resources Profile for Kabakaba Hill (HO)



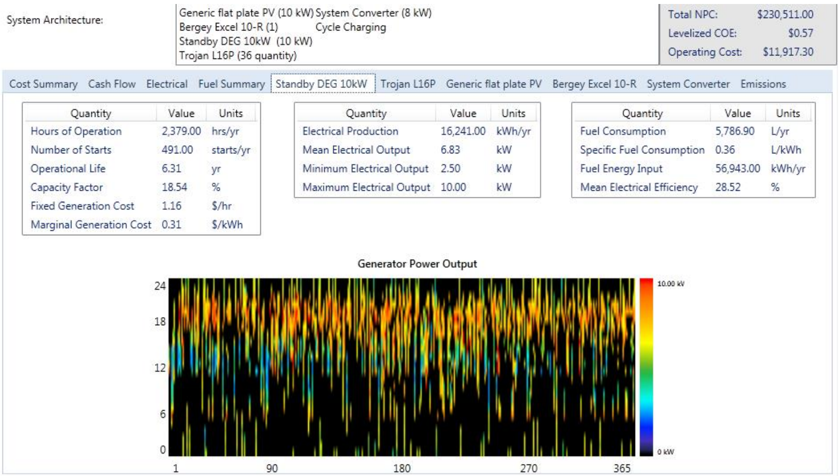
Wind Resource Profile for Kabakaba Hill (HO)



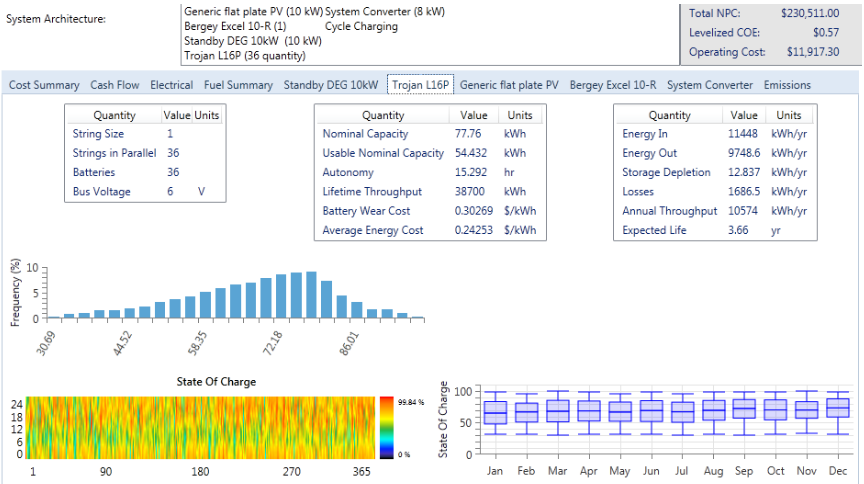
Monthly Average Electricity Production for Kabakaba Hill (HO)



Solar PV output for Kabakaba Hill (HO)

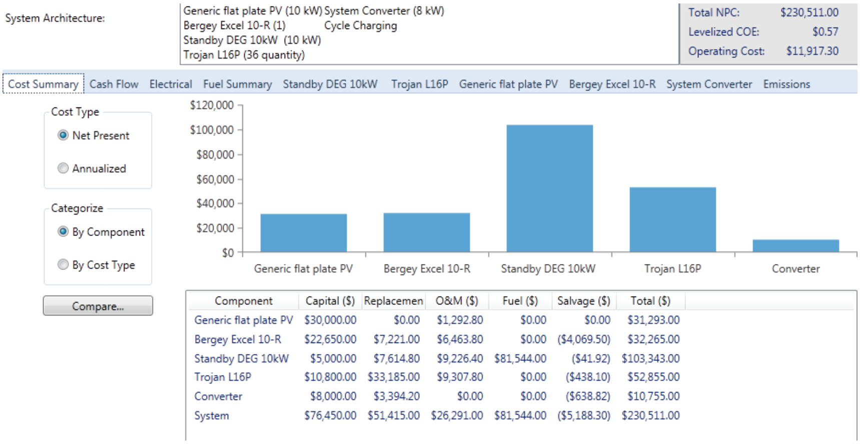


DEG output for Kabakaba Hill (HO)



Battery output for Kabakaba Hill (HO)

Converter output for Kabakaba Hill (HO)

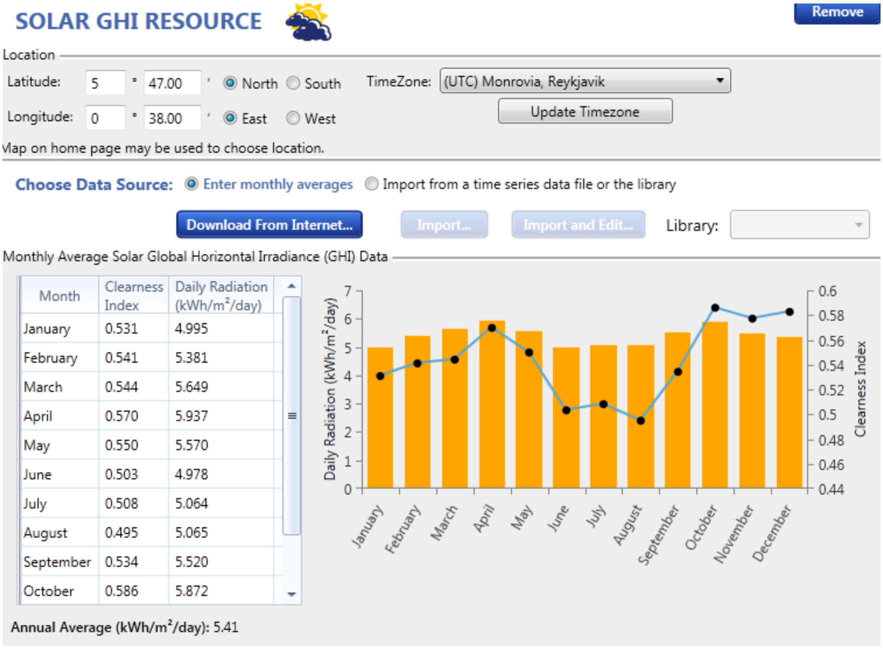


Component	Capital ($)	Replacemen	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic flat plate PV	$30,000.00	$0.00	$1,292.80	$0.00	$0.00	$31,293.00
Bergey Excel 10-R	$22,650.00	$7,221.00	$6,463.80	$0.00	($4,069.50)	$32,265.00
Standby DEG 10kW	$5,000.00	$7,614.80	$9,226.40	$81,544.00	($41.92)	$103,343.00
Trojan L16P	$10,800.00	$33,185.00	$9,307.80	$0.00	($438.10)	$52,855.00
Converter	$8,000.00	$3,394.20	$0.00	$0.00	($638.82)	$10,755.00
System	$76,450.00	$51,415.00	$26,291.00	$81,544.00	($5,188.30)	$230,511.00

COST SUMMARY – NET PRESENT PER COMPONENT FOR KABAKABA HILL (HO)

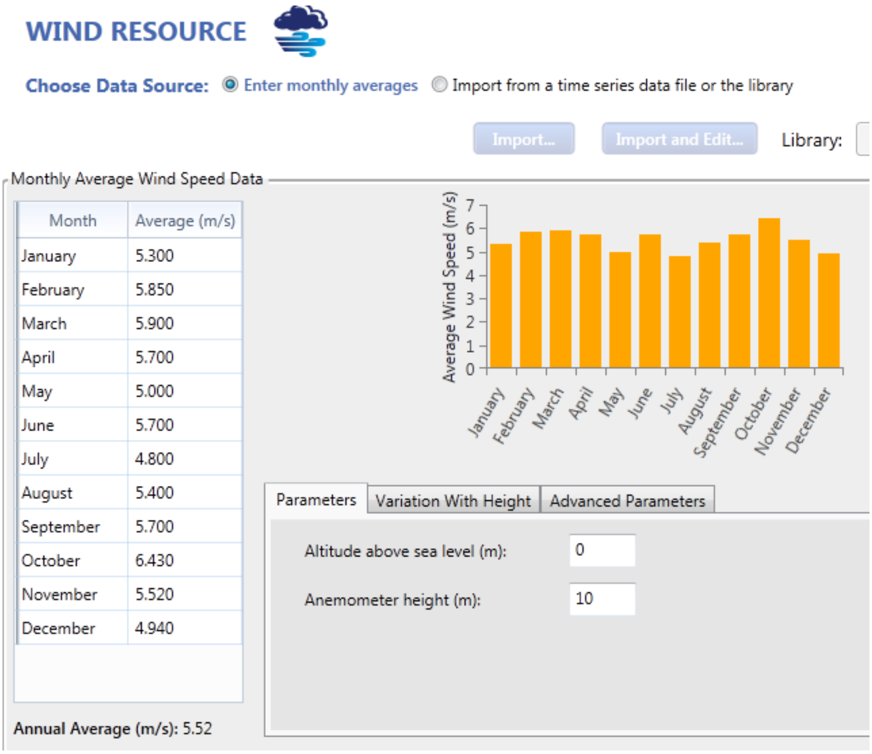
Appendix D -2: HORMER Software Simulation Results for Ada- Foah

ADA-FOAH DETAILS

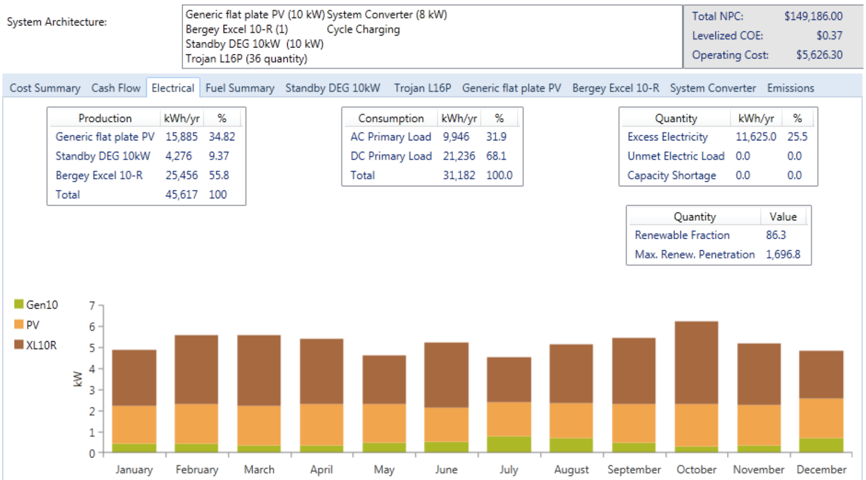


Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.531	4.995
February	0.541	5.381
March	0.544	5.649
April	0.570	5.937
May	0.550	5.570
June	0.503	4.978
July	0.508	5.064
August	0.495	5.065
September	0.534	5.520
October	0.586	5.872

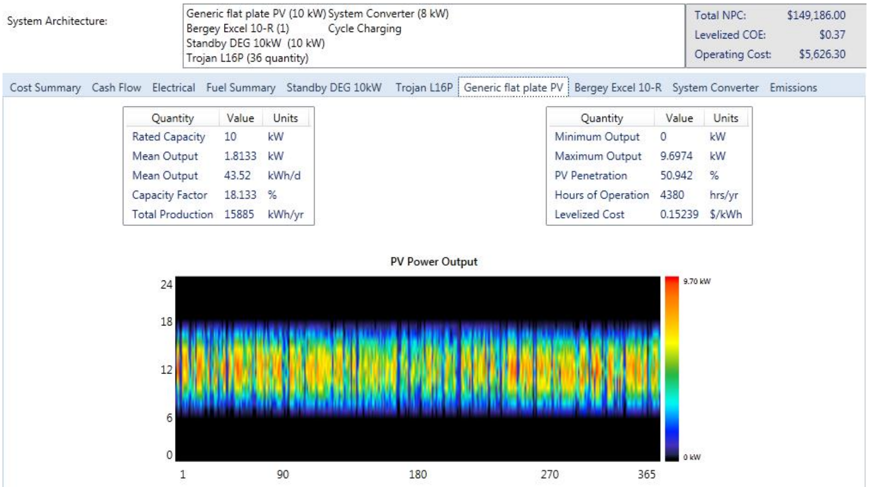
Solar Radiation for Ada-Foah



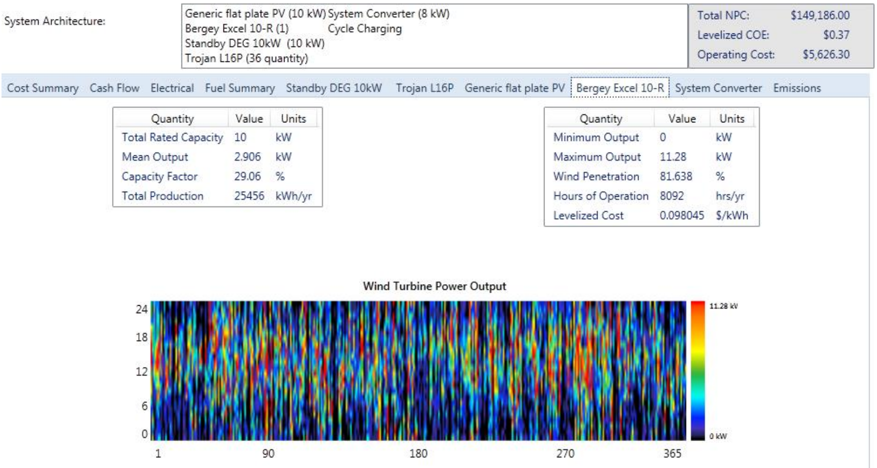
Wind resource profile for Ada-Foah



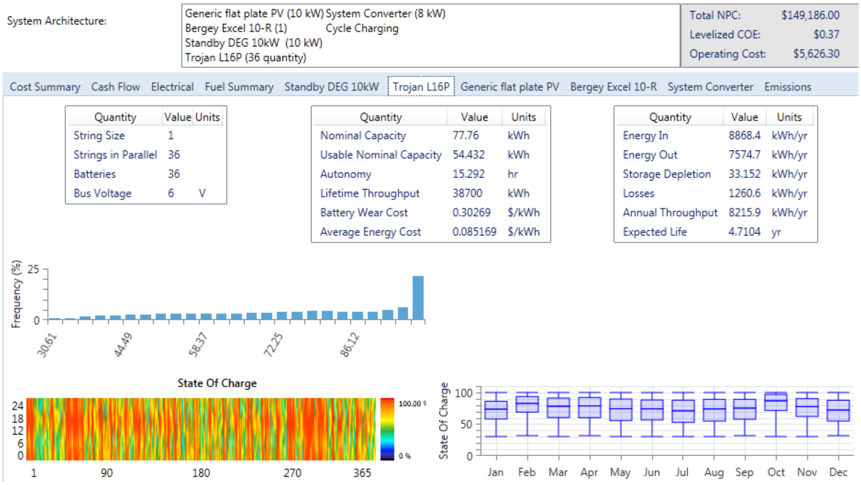
Electricity production for Ada-Foah



Solar PV operation for Ada-Foah

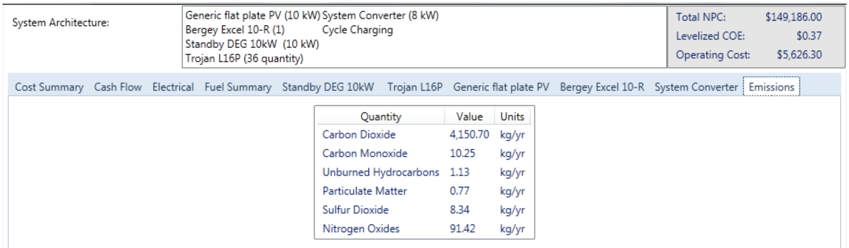


Wind Turbine operation for Ada-Foah



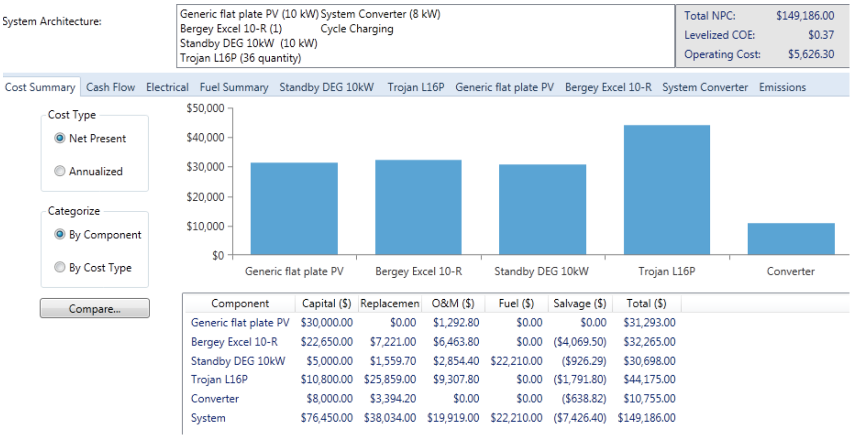
Storage Battery for Ada-Foah

Converter for Ada-Foah



Quantity	Value	Units
Carbon Dioxide	4,150.70	kg/yr
Carbon Monoxide	10.25	kg/yr
Unburned Hydrocarbons	1.13	kg/yr
Particulate Matter	0.77	kg/yr
Sulfur Dioxide	8.34	kg/yr
Nitrogen Oxides	91.42	kg/yr

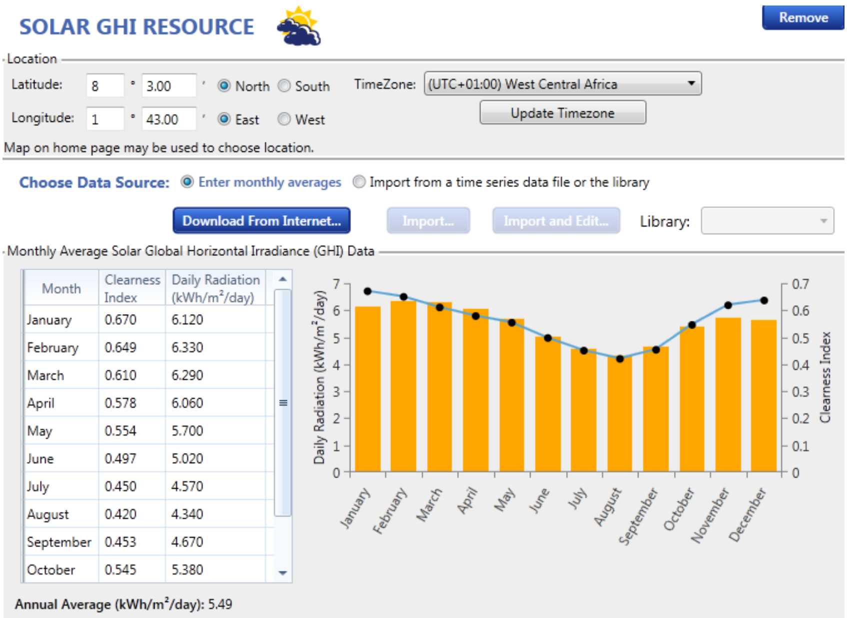
Emission from selected configuration for Ada-Foah



Component	Capital ($)	Replacemen	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic flat plate PV	$30,000.00	$0.00	$1,292.80	$0.00	$0.00	$31,293.00
Bergey Excel 10-R	$22,650.00	$7,221.00	$6,463.80	$0.00	($4,069.50)	$32,265.00
Standby DEG 10kW	$5,000.00	$1,559.70	$2,854.40	$22,210.00	($926.29)	$30,698.00
Trojan L16P	$10,800.00	$25,859.00	$9,307.80	$0.00	($1,791.80)	$44,175.00
Converter	$8,000.00	$3,394.20	$0.00	$0.00	($638.82)	$10,755.00
System	$76,450.00	$38,034.00	$19,919.00	$22,210.00	($7,426.40)	$149,186.00

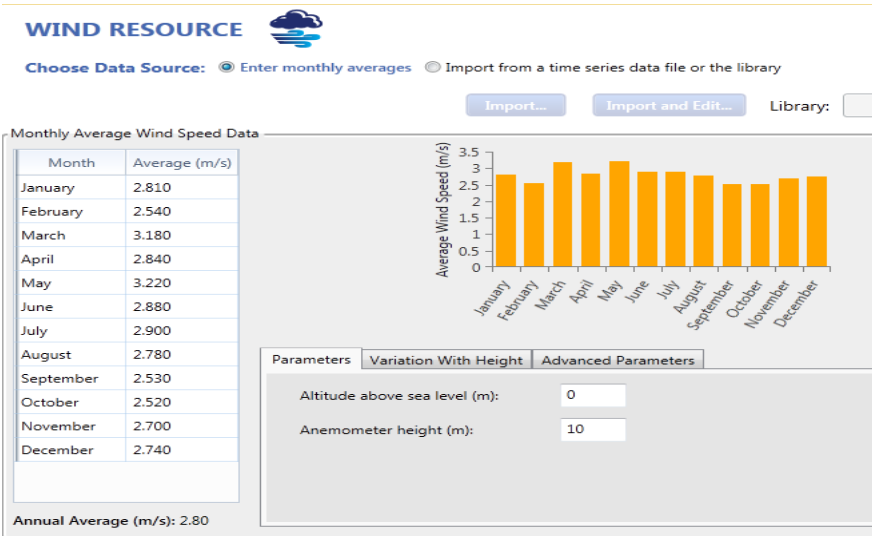
Ada-Foah Cost Summary

Appendix D - 3: HORMER Software Simulation Results for Jema



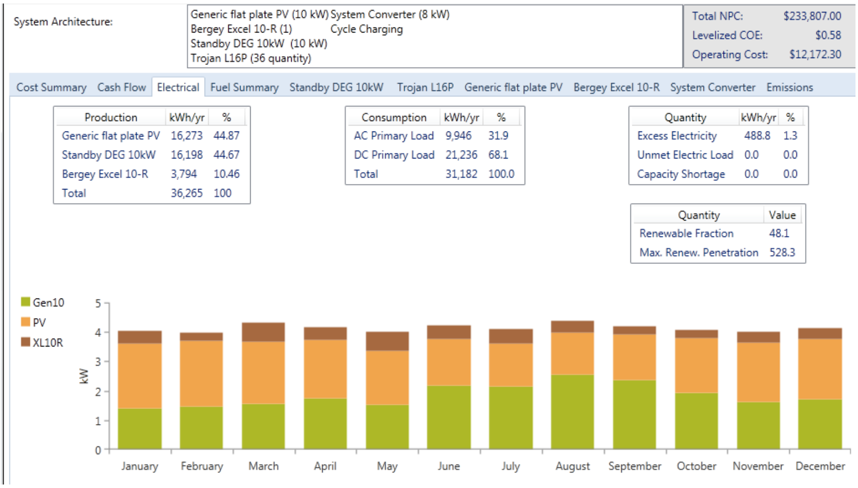
Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.670	6.120
February	0.649	6.330
March	0.610	6.290
April	0.578	6.060
May	0.554	5.700
June	0.497	5.020
July	0.450	4.570
August	0.420	4.340
September	0.453	4.670
October	0.545	5.380

Jema Solar resource profile



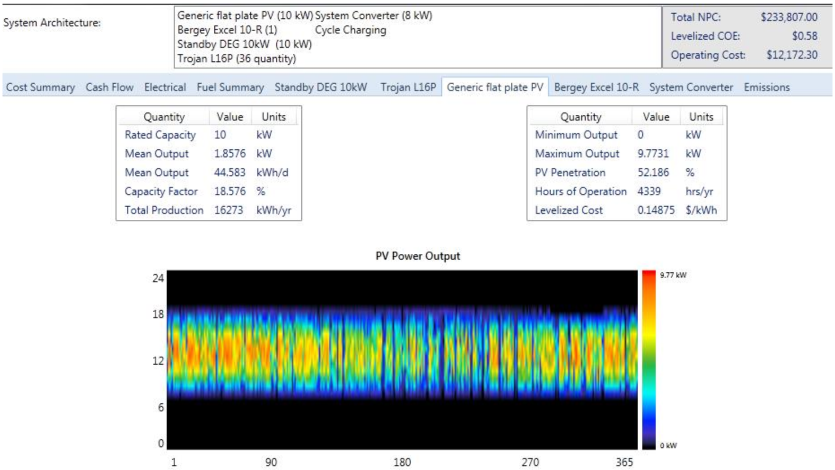
Month	Average (m/s)
January	2.810
February	2.540
March	3.180
April	2.840
May	3.220
June	2.880
July	2.900
August	2.780
September	2.530
October	2.520
November	2.700
December	2.740

Jema Wind resource Profile

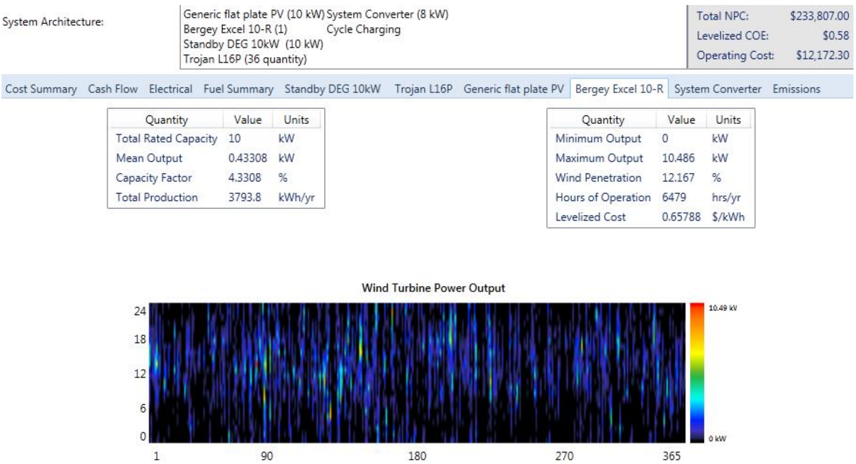


Monthly average electricity production in Jema

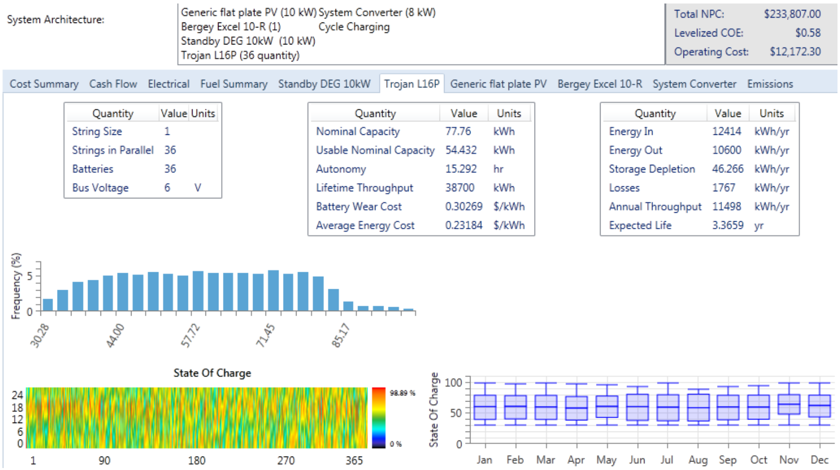
DEG output for Jema



Solar PV output for Jema

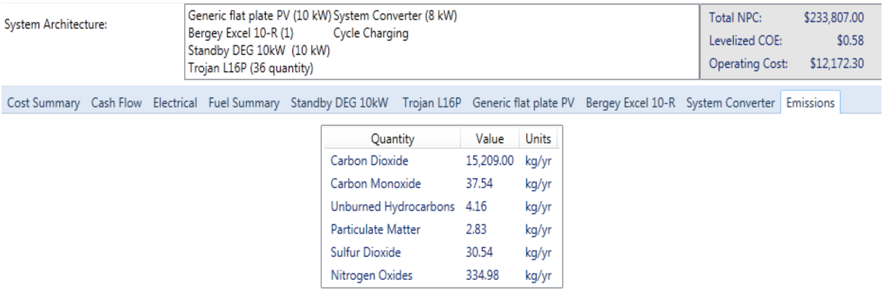


Wind Turbine output for Jema



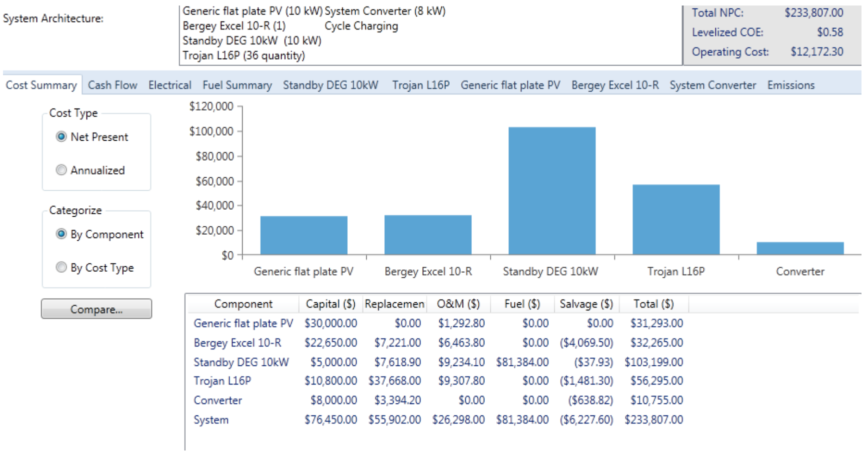
Storage Battery for Jema

Converter for Jema



Quantity	Value	Units
Carbon Dioxide	15,209.00	kg/yr
Carbon Monoxide	37.54	kg/yr
Unburned Hydrocarbons	4.16	kg/yr
Particulate Matter	2.83	kg/yr
Sulfur Dioxide	30.54	kg/yr
Nitrogen Oxides	334.98	kg/yr

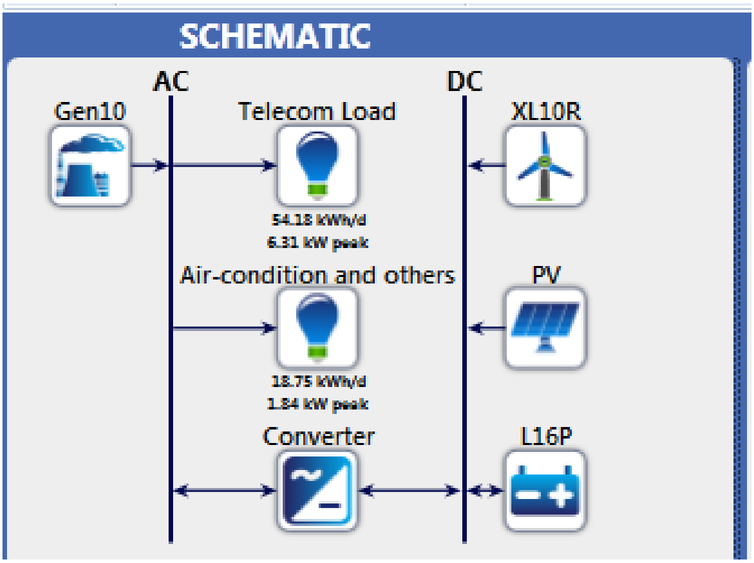
Selected Configuration emission at Jema



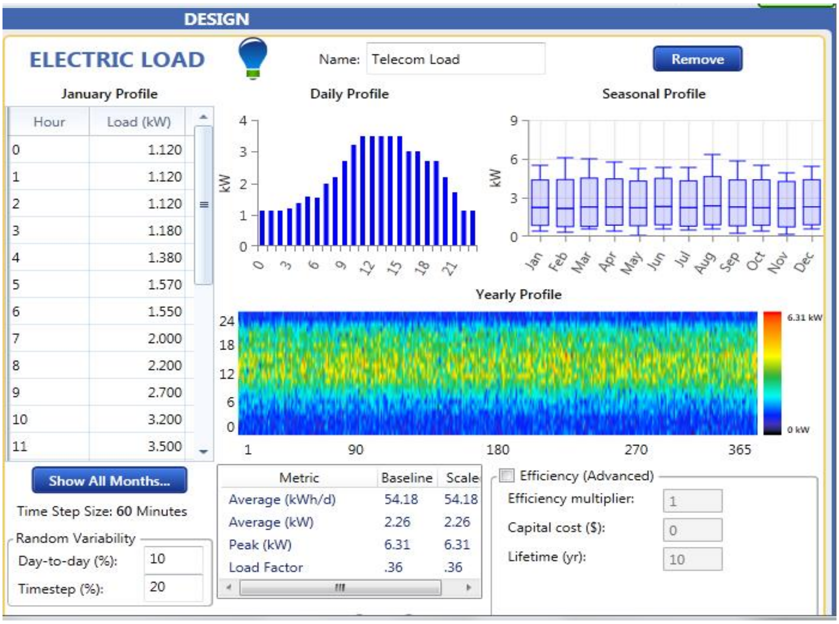
Component	Capital ($)	Replacemen	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic flat plate PV	$30,000.00	$0.00	$1,292.80	$0.00	$0.00	$31,293.00
Bergey Excel 10-R	$22,650.00	$7,221.00	$6,463.80	$0.00	($4,069.50)	$32,265.00
Standby DEG 10kW	$5,000.00	$7,618.90	$9,234.10	$81,384.00	($37.93)	$103,199.00
Trojan L16P	$10,800.00	$37,668.00	$9,307.80	$0.00	($1,481.30)	$56,295.00
Converter	$8,000.00	$3,394.20	$0.00	$0.00	($638.82)	$10,755.00
System	$76,450.00	$55,902.00	$26,298.00	$81,384.00	($6,227.60)	$233,807.00

Jema Cost summary

Appendix E: Ada-Foah Second operator results



Schematic diagram



Telecom Load profile

Ada 2nd operator other AC load

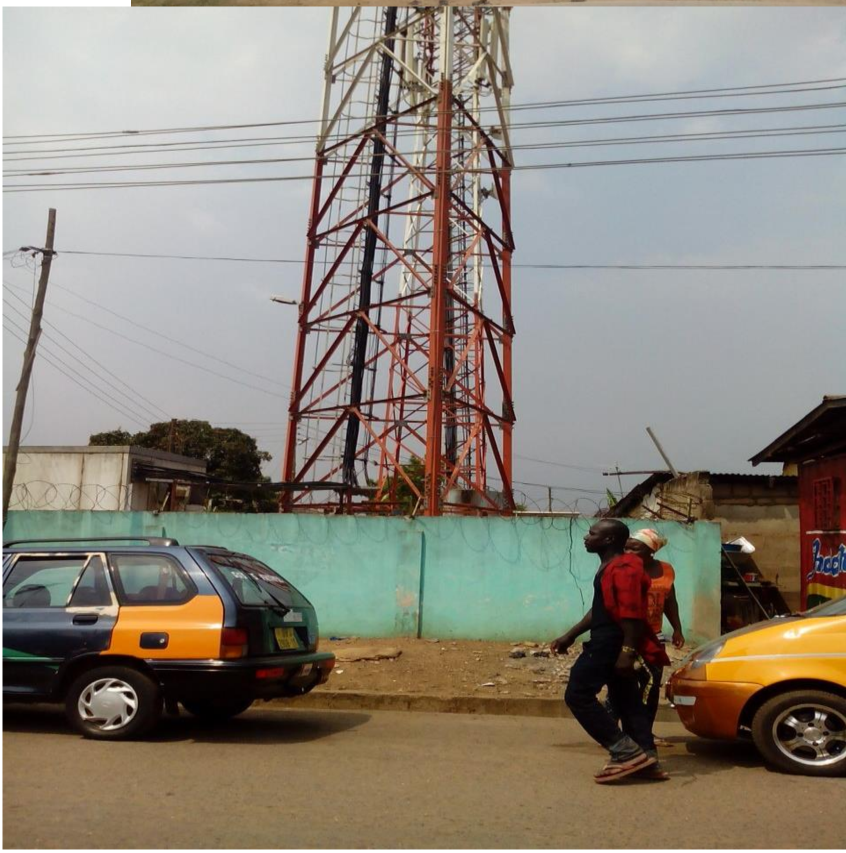
PV (kW)	XL10R (qty)	Gen10 (kW)	L16P (qty)	Converter (kW)	Dispatch	COE ($/kWh)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)	Fuel (L)	Hour
10.0	1	10	36	8	CC	$0.398	$137,078	$4,690	$76,450	90	1,009	519
10.0	1	15	36	8	CC	$0.414	$142,521	$4,918	$78,950	89.5	1,159	502
10.0	1	10	24	8	CC	$0.419	$144,140	$5,515	$72,850	84.5	1,697	1,08
5.0	1	10	36	8	CC	$0.423	$145,732	$6,520	$61,450	77.7	2,213	1,07
10.0	1	18	36	8	CC	$0.425	$146,089	$5,078	$80,450	89	1,268	501
10.0	1	20	36	8	CC	$0.431	$148,393	$5,179	$81,450	88.7	1,337	498
5.0	2	10	36	8	CC	$0.432	$148,786	$5,004	$84,100	91	906	455

Ada 2nd operator results

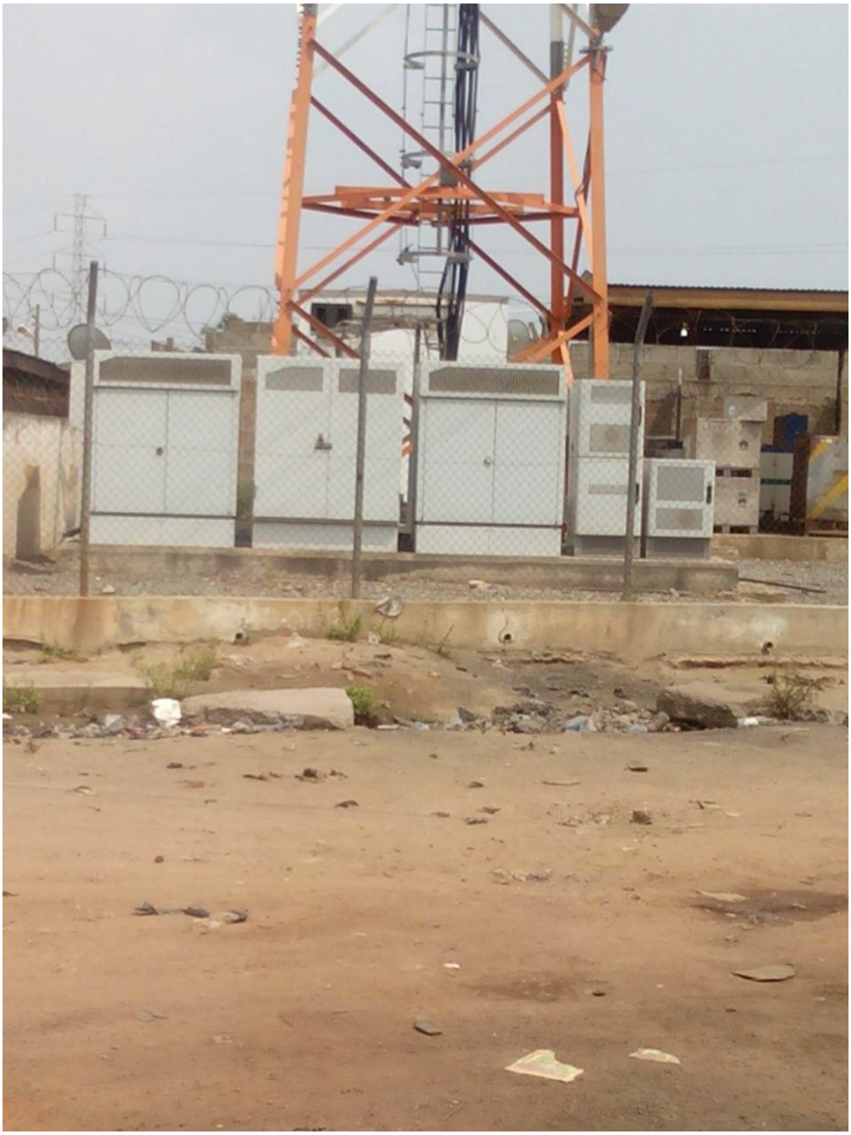
Appendix F: Some photographs at the sites


NO TRESPASSING


NO TRESPASSING




SITE NAME : ALAJO
SITE ID NUMBER
NO TRESPASS



Appendix G: Simulation of DC loads only for Ada-Foah

Sensitivity Results | Optimization Results

Double click on a system below for optimization results.

Wind (m/s)	Diesel ($/L)	PV (kW)	XLR	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
5.520	1.090	15	1		36	12	$ 45,453	2,537	$ 77,881	0.319	1.00		
5.520	1.200	15	1		36	12	$ 45,453	2,537	$ 77,881	0.319	1.00		
5.520	1.300	15	1		36	12	$ 45,453	2,537	$ 77,881	0.319	1.00		
5.520	1.400	15	1		36	12	$ 45,453	2,537	$ 77,881	0.319	1.00		
4.000	1.090	15		15	36	6	$ 27,602	5,365	$ 96,186	0.394	0.81	1,732	671
4.000	1.200	15	1	15	36	6	$ 50,252	3,726	$ 97,888	0.401	0.93	609	249
4.000	1.300	15	1	15	36	6	$ 50,252	3,787	$ 98,668	0.404	0.93	609	249
4.000	1.400	15	1	15	36	6	$ 50,252	3,848	$ 99,447	0.408	0.93	609	249
5.000	1.090	15	1		36	12	$ 45,453	2,708	$ 80,076	0.328	1.00		
5.000	1.200	15	1		36	12	$ 45,453	2,708	$ 80,076	0.328	1.00		
5.000	1.300	15	1		36	12	$ 45,453	2,708	$ 80,076	0.328	1.00		
5.000	1.400	15	1		36	12	$ 45,453	2,708	$ 80,076	0.328	1.00		
5.500	1.090	15	1		36	12	$ 45,453	2,543	$ 77,955	0.319	1.00		
5.500	1.200	15	1		36	12	$ 45,453	2,543	$ 77,955	0.319	1.00		
5.500	1.300	15	1		36	12	$ 45,453	2,543	$ 77,955	0.319	1.00		
5.500	1.400	15	1		36	12	$ 45,453	2,543	$ 77,955	0.319	1.00		
6.000	1.090	15	1		24	12	$ 41,853	2,309	$ 71,372	0.293	1.00		
6.000	1.200	15	1		24	12	$ 41,853	2,309	$ 71,372	0.293	1.00		
6.000	1.300	15	1		24	12	$ 41,853	2,309	$ 71,372	0.293	1.00		
6.000	1.400	15	1		24	12	$ 41,853	2,309	$ 71,372	0.293	1.00		
6.500	1.090	15	1		24	12	$ 41,853	2,186	$ 69,801	0.286	1.00		
6.500	1.200	15	1		24	12	$ 41,853	2,186	$ 69,801	0.286	1.00		
6.500	1.300	15	1		24	12	$ 41,853	2,186	$ 69,801	0.286	1.00		
6.500	1.400	15	1		24	12	$ 41,853	2,186	$ 69,801	0.286	1.00		
7.000	1.090	15	1		24	12	$ 41,853	2,079	$ 68,429	0.280	1.00		
7.000	1.200	15	1		24	12	$ 41,853	2,079	$ 68,429	0.280	1.00		
7.000	1.300	15	1		24	12	$ 41,853	2,079	$ 68,429	0.280	1.00		
7.000	1.400	15	1		24	12	$ 41,853	2,079	$ 68,429	0.280	1.00		

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